Book of Abstracts

26th International Conference on the Application of Accelerators in Research & Industry and 53rd Symposium of Northeastern Accelerator Personnel

October 30 to November 3, 2022
Hilton Embassy Suites in Denton, Texas, USA

CAARI-SNEAP 2022

October 30 – November 3, 2022 *Denton, TX* *www.caari-sneap.com*

Welcome to the 26th International Conference on the Application of Accelerators in Research and Industry and 53rd Symposium of Northeastern Accelerator Personnel

This conference is being hosted by the University of North Texas (UNT) in Denton, TX, Sandia National Laboratories (SNL) in Albuquerque, NM, and Livermore, CA, and Los Alamos National Laboratory (LANL) in Los Alamos, NM. CAARI-SNEAP 2022 is also being supported by several other U.S. National Laboratories, industries and agencies most identified with accelerator technology.

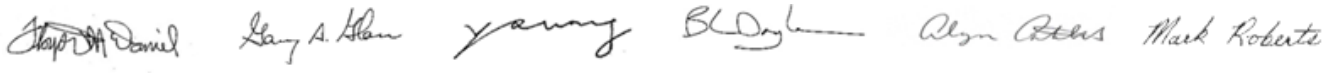
Our conference series is unique in that it brings together researchers from all over the world who use particle accelerators in their research and industrial applications. Each year the Topic Areas are reviewed and updated to reflect current research interests.

A note here for history buffs: This is the 26th International conference in the biennial series that began in 1968 as a *Conference on the Use of Small Accelerators for Teaching and Research* by Jerry Duggan while he was a staff member at Oak Ridge Associated Universities. When Jerry moved to Denton, TX, and joined UNT, he continued the Conference series in 1974, holding the meeting on the UNT campus. At this time, Jerry invited Lon Morgan to join him as a co-chair. Lon Morgan brought in the industrial components of CAARI and it became known as the International Conference on the Application of Accelerators in Research and Industry (CAARI). CAARI was held in Denton for 30 years. In 2004, Jerry Duggan asked Floyd "Del" McDaniel and Barney Doyle to be co-chairs of the CAARI Conference Series. In 2004, Barney and Del moved the conference to Fort Worth, Texas, where it was held biennially from 2004-2012. In 2012, Yongqiang Wang and Gary Glass were invited to become co-chairs and the conference was held in San Antonio, TX. For the 2016 Conference, Arlyn Antolak joined as a co-chair and the conference returned to Fort Worth, Texas. Our 2020 conference was cancelled due to the Covid pandemic.

The Symposium of Northeastern Accelerator Personnel (SNEAP) is an international community of personnel involved with electrostatic particle accelerators and their use. Founded in 1968, the organization has gathered annually to discuss and exchange information to the benefit of all those who attend. Topics covered include ion sources, electrostatic and rf accelerators, telemetry and control systems, cryogenic systems, safety issues and many other topics relevant to the operation of small to medium sized electrostatic accelerator laboratories.

We hope that you enjoy the conference and find it intellectually stimulating. In the schedule, we have provided several opportunities to renew friendships and talk science at this meeting. In addition, a program book entitled *Book of Abstracts,* which contains an abundance of conference information, may be found at CAARI-SNEAP.com.

If there is anything we can do to make your conference experience and stay in Denton, Texas, more enjoyable, just ask Gary, Del, Yong, Barney, Arlyn, Mark, Holly, Carley or Shari. We are very happy you have joined us and hope you have a memorable time!



F.Del McDaniel[a] Gary Glass[a] Yongqiang Wang[b] Barney Doyle[c] Arlyn J. Antolak[c] Mark Roberts[d]

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1155 Union Circle, # 311427 * Denton, Texas 76203-5017 USA Email: CAARI2022@outlook.com

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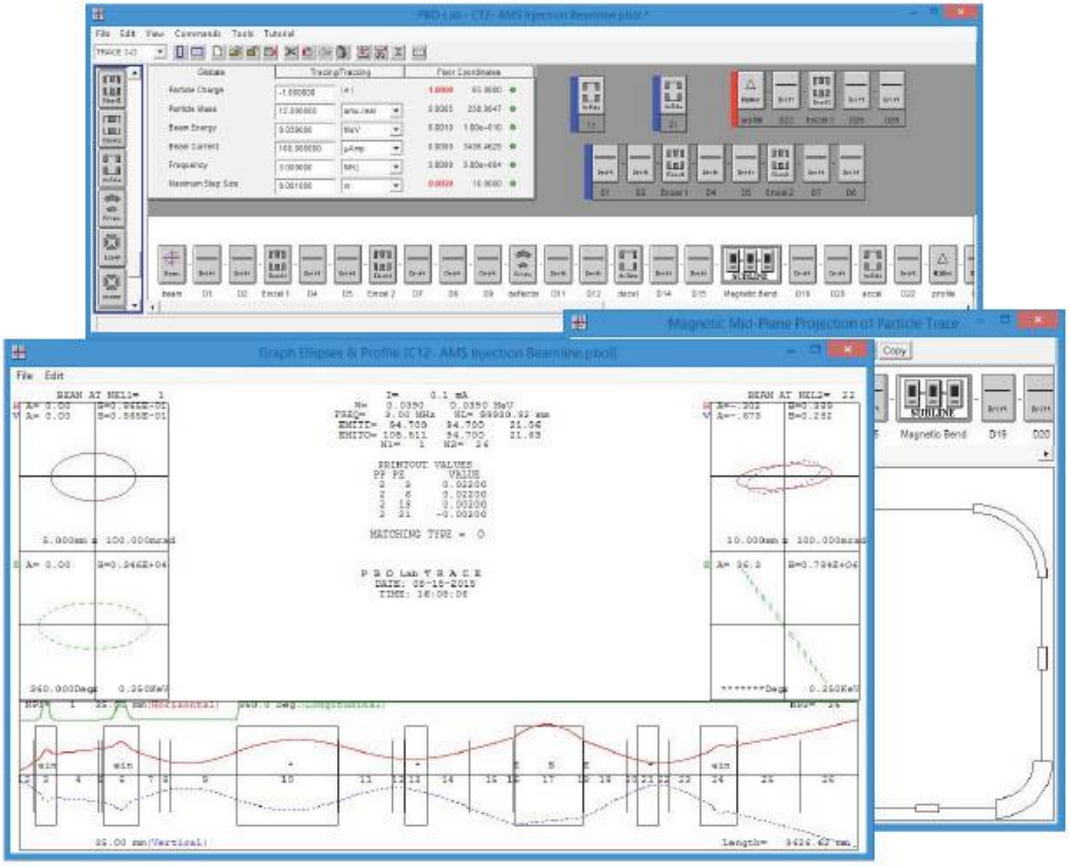

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- SF_6-insulated Tandetron Tandem Ion Accelerators with TV up to 6.0 MV
- Vacuum-insulated Tandem Ion Accelerators with TV up to 300 kV

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- Singletron Electron Accelerators with TV up to 6.0 MV/TV

Ion Implanters

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Ion Beam Analysis Systems

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- Particle Induced X-ray Emission (PIXE)
- Particle Induced Gamma-ray Emission (PIGE)
- Nuclear Reaction Analysis (NRA)
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- Archeology
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- Biomedicine
- Etc.

Ion Microbeam Systems

- Tandetron and Singletron based Systems

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Event and Session Schedules

Up-to-date event schedule is available at https://caari-sneap.com/event-schedule

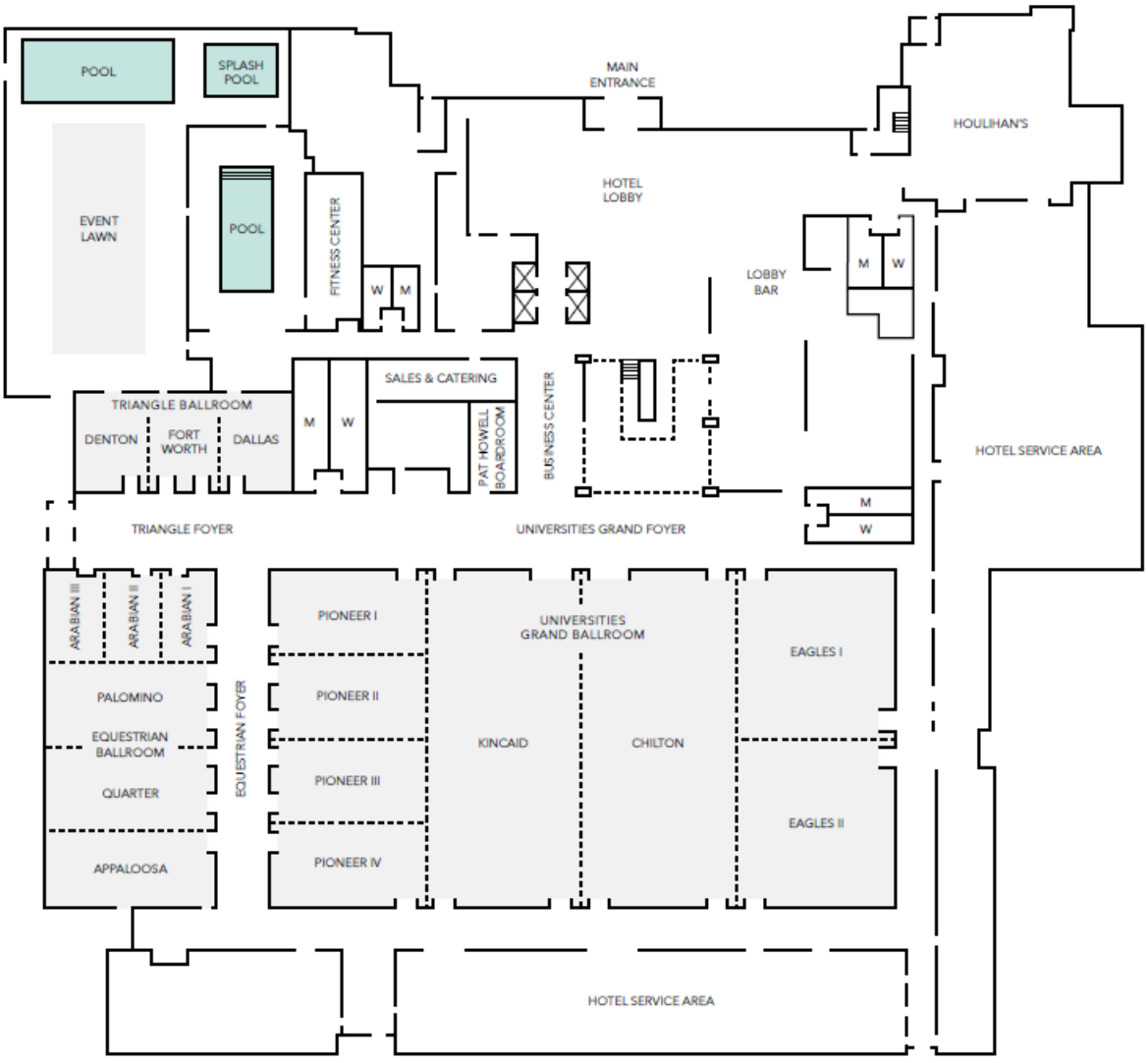
Up-to-date session and speaker schedule is available at https://caari-sneap.com/session_schedule

The session schedule is also available organized by topics and sessions at
https://meeting247.com/caari-sneap/pub/session-category-list.action

Embassy Suites by Hilton

Map of the CAARI-SNEAP conference rooms

FIRST FLOOR



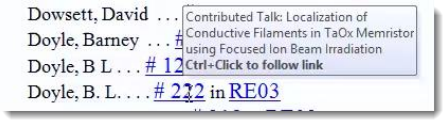
Using this Book of Abstracts

This Abstract Book contains:

1. the session summary,
2. full text of accepted abstracts, and
3. the index of authors and co-authors.

The Abstract Book can be downloaded from the conference website at https://caari-sneap.com/ and is available in several formats. All formats feature mutual hypertext links between the schedule, abstracts, and the author index.

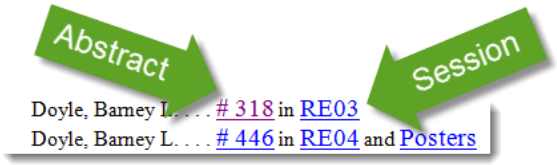
- Laptop or desktop users: the Microsoft Word version offers popup hints - to see them, please, hover the mouse over the hyperlink. Alternatively, a PDF version is also available.



- Users of small mobile devices (tablets or smartphones): While you can certainly use the desktop Word and PDF versions if your device supports them, we have re-flown the Abstract Book to about 4“ width so that if you are viewing the book you do not need to shift the screen horizontally. The mobile version of the Adobe Reader can be downloaded from the corresponding app stores, for example, from Google Play for Android.

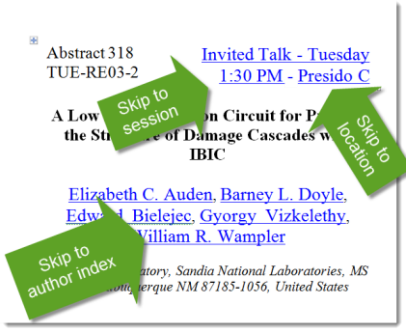
Subject to the type of software you chose to view this Book of Abstracts, you will be able to search for keywords in the abstracts that relate to your areas of interest or add your own notes or bookmarks.

This listing contains information about each presentation including all of the authors and their affiliations. If you wish to find out, for example, when Barney Doyle’s talk is to be given, just look up his name in the author index at the end of this book:



Then click on the abstract number to read the full abstract or the session code to view other presentations in the same session.

When you are viewing the abstract click on the author’s name to skip to the author index again or click on the session time and location to see all other presentations in this session.



The abstract details include the abstract number: 318
The type of presentation: Invited Talk
The day and time Session RE03 starts: Tuesday 1:30 PM
The location: Presidio C

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Session Summary

Please note: the presentations marked (Poster session) in the listing below will be presented during the poster sessions only. They are listed at the end of each talk session only to provide the session context.

Disclaimer: Last minute changes happen. The session times and locations listed here may not reflect these latest changes. Before coming to the session always verify the current speaker and session schedules posted at the conference website at https://caari-sneap.com/

PS-AP-01: Development of a new FLASH treatment machine: Phaser

Monday at 8:45 AM in Kincaid

237 FLASH: a new paradigm in cancer radiation therapy and novel technology for its clinical translation *by Bill W. Loo*

AA-IBTM-01: MeV SIMS and IBA

Monday at 10:00 AM in Kincaid (Hybrid)

51 Optimization of MeV ToF SIMS in the low primary ion beam energy mode for the analysis of inorganic materials *by Marko Barac*
249 Probing the Ion Migration in 3-D Triple-Cation Perovskite Solar Cells via Rutherford Backscattering Spectrometry *by Mritunjaya Parashar*
248 Trace-elemental analysis of herbal plant leaves using Particle Induced X-ray Emission *by Darshpreet Kaur Saini*

AC-AF-01: Accelerator Facility Updates (major, larger scale)

Monday at 10:00 AM in Pioneer III

102 Beam Commissioning and Setup for the First User Experiments at FRIB's Advanced Rare Isotope Separator *by Kei Fukushima*
125 Radiation Effects Facility at the Texas A&M University Cyclotron Institute *by C. E. Parker*
234 The European Ion Beam Centers Network RADIATE *by Stefan Facsko*
225 Workforce training in accelerator science and engineering provided by the US Particle Accelerator School and DOE Traineeships *by Steven Lund*

AP-IA-01: Geo-Physical and Non-Destructive Testing Applications

Monday at 10:00 AM in Quarter

253 Compensated Neutron Logging Tool Using nGen® D-D Neutron Generator for Am-Be Replacement *by Brian Jurczyk*
205 Finding hydrocarbons with neutrons: The physics and technology of neutron-induced gamma-ray spectroscopy in the oil patch and beyond *by Richard Radtke*
173 Effect of Hydrogen gas on the field emission properties of carbon nanotubes film *by Marie Quentin Schindler*

AR-NST-01: Focused Ion Beam Implantation for Defect Centers and Sensing - a Sandia Perspective

Monday at 10:00 AM in Arabian

239 Focused Ion Beam Capabilities for Solid-State Color Center Formation at Sandia's Ion Beam Laboratory *by Michael Titze*

228 Fabrication of Novel Ion Sources for Nanoimplantation *by Aaron M. Katzenmeyer*
119 Creation of Deterministic Single Photon Emitters by Focused Ion Beam and In-situ Photoluminescence *by Vignesh Chandrasekaran*
88 Long range collective interactions of rare earth ion arrays precisely implanted inside photonic resonators *by Yisheng Lei*

PR-SP-01: Nuclear Astrophysics I

Monday at 10:00 AM in Palomino

153 ONe Nova Nucleosynthesis Studies Using ^{31}Cl β-Delayed Proton Decay *by Tamas Budner*
136 Experimental study of ^{19}Ne excited states relevant for classical novae using the Enge split-pole spectrograph at TUNL *by Federico Portillo*
130 ODeSA and the ^{18}O(α,n)^{21}Ne Reaction *by Rebecca Toomey*
57 Study of states near E_x=6 MeV in ^{18}Ne for the ^{14}O(α,p)^{17}F reaction rate *by Sudarsan Balakrishnan*
158 The CASPAR underground facility for nuclear astrophysics research, results and future directions *by Daniel Robertson*

SN-SSR-01: Status Reports I

Monday at 10:00 AM in Pioneer IV

129 New Developments at the Louisiana Accelerator Center *by William Andrew Hollerman*
116 Status Report for Notre Dame's Nuclear Science Laboratory *by Edward Stech*
95 Laboratory Report discussing upgrades to the FN Tandem and the upgrading of the TUNL Low-Energy Nuclear Astrophysics Laboratory - Replacing the JN Van de Graaff with a new 2 MV Singletron. *by Chris Westerfeldt*
11 ANSTO Centre for Accelerator Science Status Report *by David Garton*

AC-AF-02: Accelerator Facilities (smaller scale at Universities, Industry, Medicine)

Monday at 12:30 PM in Pioneer III

72 Developments at at the Australian National University's Heavy Ion Accelerator Facility *by Peter Linardakis*
163 Construction of an Electron Cyclotron Emission Imaging System *by L. E. Henderson*
270 Harnessing the Full Capacity of the Shady Oaks LINAC for Isotope Production *by Lin Shao*
246 Ion Beam Irradiation and Analysis facilities at the University of North Texas *by Bibhudutta Rout*

AP-MA-03: Recent advances in particle beam radiobiology and radiochemistry

Monday at 12:30 PM in Quarter

274 The future of radiotherapy is charged particles: Exploiting physics and biology for precision medicine. *by Michael Dean Story*
262 Charged particle radiosensitization and radioprotection strategies: flip of a coin *by Paul F. Wilson*
195 LET-Based Proton Planning - From Development to Clinical Implementation *by Wei Liu*
134 Design and Execution of Experiments on Long Duration Irradiation of Uranyl Sulfate Solution for Mo-99 production *by Sergey Chemerisov*

AP-SD-01: Security and Defense

Monday at 12:30 PM in Palomino

58 (Poster session) Detection of shielded special nuclear materials and other contraband by using portable, high-flux DD and DT neutron generators *by Xianfei Wen*

267 (Poster session) Light-Ion Production of Gold Radioisotopes from Natural Platinum Targets *by John Wilkinson*
40 High Performance Silicon Drift Detectors for synchrotron applications *by Andrew Jarrett*
41 RSim: A Monte Carlo simulation application with CAD capability, Geant4 for radiation modeling, and visualizable mesh scoring *by David A. Alexander*
87 Photofission Neutron Detection with Neural Network based Digital Pulse Processing. *by Abbas Johar Jinia*

AR-NST-04: Nanoscale Pattern Formation Produced by Ion Bombardment of Solid Surfaces, Part I

Monday at 12:30 PM in Arabian

215 In-situ observation of ion-induced nanoscale patterning on a crystalline Ge(001) surface *by Stefan Facsko*
23 Atomistic mechanisms of nanoripple formation under tilted low energy ion irradiation *by Flyura Djurabekova*
25 Simulation of low energy ion-solid interactions using the binary collision approximation *by Hans C Hofsaess*

SN-STDS-01: Technical Developments I

Monday at 12:30 PM in Pioneer IV

216 (Poster session) 3 MeV Pelletron Facility at Sandia National Laboratories *by George R Burns*
113 Modification of an H^- Ion Source for the Extraction of Negative and Positive Ions *by Stephane Melanson*
106 Preparation for the transfer of accelerator laboratory and installation of the new 5 MV Tandetron at RBI *by Fares Boussahoul*
59 Conducting Self-Ion Irradiation Experiments in Candidate Core Structural Materials at the Michigan Ion Beam Laboratory *by Prashanta Niraula*
22 Uplifting ANSTO Tandem Accelerator Facilities for the Future *by David Button*

AC-TD-02: Emerging Accelerator Technologies

Monday at 2:30 PM in Quarter

260 (Poster session) Innovative Magnetron Power Sources for Superconducting Accelerators *by Mary Anne C Cummings*
177 On-chip Integrated Laser-driven Particle Accelerators *by Robert Joel England*
182 Laser-ion sources for multidisciplinary research applications *by Lieselotte Obst-Huebl*
104 Compact Multi-beam Radio-frequency Linear Ion Accelerators *by Thomas Schenkel*
217 Recent Activity at National Electrostatics Corp. *by Stephanie Stodola*
61 D-Pace UniBEam Beam Profiler Integration and High Beam Power Scan Data at the University of Washington Medical Cyclotron Facility *by Marissa Kranz*
273 K-Modules: Capacitive energy modules for pulsed power applications *by Kalpak Arvind Dighe*

AP-TA-01: Undergraduate Education and Experiments with Accelerators

Monday at 2:30 PM in Pioneer III

188 2022 First Year Pre-Orientation Program activites of the MIT Department of Nuclear Science and Engineering *by Kevin Benjamin Woller*
63 Undergraduate Research at the Cyclotron Institute at Texas A&M *by Lauren McIntosh*
269 Enhancing the Undergraduate Advanced Lab experience: Measuring Photons and Ions *by RAHUL MEHTA*

145 Nuclear Labs for Undergraduates and High School Students Using a Low-Cost Gamma Spectroscopy System and Other Educational Activities at Tarleton's Nuclear Laboratory *by Daniel Keith Marble*

AR-ISM-02: Mechanical properties of ion irradiated complex alloys

Monday at 2:30 PM in Kincaid (Hybrid)

47 (Poster session) Optical properties of SiGe nanocrystals in SiO_2 produced by ion implantation *by Matheus C. Adam*

71 (Poster session) The Impact of SHI Irradiation on the Low-Temperature Dielectric Phase Transition in $K_2Bi_4Ti_4WO_{18}$ *by Vipul Kumar Sharma*

74 Understanding of the evolution of mechanical properties of steels under irradiation: micromechanics and microstructure *by cristelle pareige*

240 The key role of heavy ion irradiation in the development of ductile amorphous oxide barrier coatings for next generation nuclear power plants. *by Fabio Di Fonzo*

254 Computing stress and strain fields resulting from exposure of materials to neutron or ion irradiation: from microscopic models to FEM of reactor components *by Sergei Dudarev*

222 Development and mechanical properties of multicomponent thin films from the Cr-Hf-Mo-Ta-W system designed for harsh environments *by Tomasz Stasiak*

245 Short-range order in ion-irradiated NiCoCr medium entropy alloys *by Lukasz Kurpaska*

AR-NST-05: Nanoscale Pattern Formation Produced by Ion Bombardment of Solid Surfaces, Part II

Monday at 2:30 PM in Arabian

79 Coherent X-ray Scattering as a New Tool for the Study of Ion Beam Nanopatterning *by Karl Ludwig*

53 Theory of Nanoscale Patterns Produced by Ion Bombardment of Solid Surfaces *by R. Mark Bradley*

191 Compositional Changes Under Low-Energy Ion Beam Irradiation of Disordered Alloys *by Jean Paul Allain*

AR-RE-01: Accelerator-based Irradiation capabilities for Nuclear Energy Research

Monday at 2:30 PM in Pioneer IV

85 Experiment with simulation studies of heavy ion radiolysis of aqueous systems *by Simon M Pimblott*

230 In situ monitoring of heavy liquid metal and molten salt corrosion under simultaneous irradiation with particle-induced x-ray emission (PIXE) spectroscopy *by Franziska Schmidt*

75 High Throughput Study of Hardening, Void Swelling and Corrosion in Ion Irradiated High Entropy Alloys *by Hongliang Zhang*

219 Using a Small Pelletron to Simulate Space Radiation for CAPE *by John Miller*

PR-SP-02: Nuclear Astrophysics II

Monday at 2:30 PM in Palomino

16 β-Oslo measurements for the r-process with next generation accelerator facilities *by Erin C Good*

65 Mass measurements for the r-process using Canadian Penning Trap *by Biying Liu*

143 Study of $^{86}Kr(\alpha, n)$ in inverse kinematics using SECAR *by Caleb Marshall*

92 High power DC and nanosecond pulsed 2 MV accelerator for light ions *by Rob Walet*

55 New Tools for Explosive Nucleosynthesis Studies at the Notre Dame Nuclear Science Lab (NSL) *by D. W. Bardayan*

PS-AC-01: Spallation Neutrons and Applications

Tuesday at 8:45 AM in Kincaid

190 Spallation Neutrons and Applications *by Kenneth Herwig*

AP-IA-02: Advanced Accelerators for Medical/Insect/Pharmaceutical Sterilization and Blood/Food Irradiators

Tuesday at 10:00 AM in Quarter

261 Reducing the Radiological Risk by Encouraging Electron Beam and X-Ray Adoption *by Jennifer Elster*

279 The use of Electronic Cold-Pasteurization (ECP) as a means of reducing movement and development of plant pests and pathogens *by Chip Starns*

218 Comparison and Selection of Irradiation Sources for Medical Device Sterilization and Environmental Applications *by David Staack*

AP-SD-02: Neutron Generators Security and Defense

Tuesday at 10:00 AM in Pioneer III

108 Neutrons for Border Security: A Customer's Viewpoint *by Philip N Martin*

160 Cargo Inspection Using Neutron Generators *by Martin B. Smith*

80 Vehicle-based and Robotic Active Neutron Interrogation Systems for Threat Detection *by Michael J. King*

94 DT Neutron Generators for Security and Defense Applications *by Jay Theodore (Ted) Cremer*

178 (Poster session) Time-Resolved Digital Data Analysis for Neutron Active Interrogation *by Abbas Jinia*

AR-NST-06: Nanoscale Pattern Formation Produced by Ion Bombardment of Solid Surfaces, Part III

Tuesday at 10:00 AM in Arabian

30 The multiple impactful applications of ion beam bombardment *by Carmen S. Menoni*

179 Defect engineering in Ga_2O_3 by ion beam irradiation and band gap tunning *by Farida A. Selim*

156 Isotropic swelling as a mechanism for nanopattern suppression *by Scott A Norris*

161 Physical mechanisms affecting critical angle for nanopatterning in irradiated semiconductors *by Tyler Evans*

AR-RE-06: Radiation Effects in Nanostructured Materials

Tuesday at 10:00 AM in Kincaid (Hybrid)

201 Radiation effects in MAX phases *by Chenxu Wang*

208 The contribution of irradiation effect in ferromagnetic semiconductors *by Ye Yuan*

206 Self-powered and flexible gas sensor using defect-engineered 2D heterostructure *by Yang Tan*

32 Enhanced (Photo)electrocatalytic properties by ion beam technology *by Feng Ren*

PR-SP-03: Atomic Nuclear and Molecular techniques for fundamental physics I

Tuesday at 10:00 AM in Palomino

45 The Nuclear Pear Factory *by Jaideep Taggart Singh*

199 Infrastructure for radioactive molecule production at CERN-ISOLDE *by Sebastian Rothe*

200 Developments for actinide molecular ion beams at CERN-ISOLDE *by Mia Au*

98 Optimized high-throughput analysis technique for a dual-axis duo-lateral position-sensitive silicon detector for excellent position and energy resolution *by Andy Hannaman*

SN-STDS-02: Technical Developments II

Tuesday at 10:00 AM in Pioneer IV

258 (Poster session) Capability of 6MV Tandem Accelerator Facility at Sandia National Laboratories *by Armin de Vera*
250 Repairing of Rust Induced Vacuum degradation of a Switching Magnet Chamber *by Mohin Sharma*
211 Calculating Charge State Distributions of Beams Accelerated by Tandem Accelerators *by Barney L. Doyle*
123 Laser-assisted negative ion production in caesium sputter negative ion source *by M. Laitinen*

AA-IBTM-03: Multiple technique analyses including ion beams (TOTAL IBA)
Tuesday at 12:30 PM in Kincaid (Hybrid)

193 (Poster session) Exploring new methods to monitor proton beam damage for sequential elemental and molecular imaging on a single tissue section *by Catia D S Costa*
194 Sequential molecular and elemental imaging on a single tissue section using DESI and PIXE *by Catia Costa*
233 Application of multiple ion beam analysis techniques in plant biology and nutritional science *by Bostjan Jencic*
39 Colocation of Lipids, Drugs, and Metal Biomarkers Using Spatially Resolved Lipidomics with Ion Beam Elemental Mapping *by Melanie J Bailey*

AP-TA-02: Graduate Programs I
Tuesday at 12:30 PM in Pioneer III

127 Probing nuclei with neutrons at UKAL through research designed to maximize student contributions and collaborations *by S. F. Hicks*
27 Developing a Remote Gamma Spectra Collection System for Radiation Sciences at the University of Nevada Las Vegas *by Zaijing Sun*
128 Teaching a Graduate-Level Ion Beam Course at the Louisiana Accelerator Center *by William Andrew Hollerman*

AR-NST-02: Defect Centers in Wide Bandgap Substrates - Creation and Applications
Tuesday at 12:30 PM in Arabian

144 Coherent Optical Spectroscopy Studies of Hidden Silicon-Vacancy Centers in Diamond *by Christopher L Smallwood*
154 Measuring Strain and Coherent Interactions in an Ensemble of Silicon-Vacancy Centers in Diamond *by Kelsey M. Bates*
148 Effects of Ion Implantation Damage on Photoluminescence of Silicon-Vacancy Centers in Diamond *by Stephen Revesz*

AR-RE-02: Multiscale Studies of Irradiated Materials for Fusion Applications
Tuesday at 12:30 PM in Quarter

209 Beam-On Effects in Nuclear Materials for Generation IV Fission and Fusion Reactors *by Michael P Short*
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99 Focused ion beam applications using gas field and liquid metal alloy ion sources *by Gregor Hlawacek*
90 Simulation of ultra-low energy ion implantation of 2D materials *by Hans C Hofsaess*
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164 (Poster session) Comparison of PIXE and XRF Results on Ancient Egyptian Bronze Artifacts *by Benjamin Lukk*
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151 Ion Beam Analysis of Ancient North and West African Metals and Glass *by Stewart Bragg Younger-Mertz*
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107 Creation and characterization of diamond color centers by means of ion beam implantation *by Sviatoslav Ditalia Tchernij*
78 On the Use of SRAM Based Dosimeters to Measure LET and Fluence in Heavy Ion Facilities *by Ryan Dean Rinderknecht*
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121 ToF-ERDA - New detectors, New spectrometer *by Mikko Laitinen*
77 Methods for External Proton Induced Gamma and X-ray Emission (PIGE and PIXE) *by Gunnar McAndrews Brown*
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192 An in silico method for the determination of crystalline defect relaxation volumes - bcc Fe as a test-case *by Mohamed El-Bakouri El-Haddaji*
284 Novel Refractory High Entropy Alloys for Applications in Extreme Environments *by Osman El Atwani*
231 Interface effect of Fe and Fe_2O_3 on the distributions of ion induced defects *by matthew chancey*
283 Novel Refractory High Entropy Alloys for Applications in Extreme Environments *by Osman El Atwani*

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155 (Poster session) Ion Beam Analysis of a Cerium(III) Tris[bis(trimethylsilyl)amido] Phosphine Oxide Crystal *by Stewart Bragg Younger-Mertz*
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96 Adding "color" to Helium Ion Microscopy images *by Gregor Hlawacek*
180 Design of an electrostatic focusing system for low MeV multi-ion micro-beam *by Harsh Arya*
183 Ion and neutral time-of-flight spectroscopy for deciphering the composition and structure of plasma-facing materials *by Robert D Kolasinski*

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132 Quantifying Carbon Sequestration using Associated Particle Imaging *by Caroline Egan*
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Accelerator-Driven Reactors *by Mary Anne C Cummings*
167 (Poster session) Accelerator-Based Fusion Fuel Options for Using an Artificially Structured Boundary *by Kelly Wood*
138 (Poster session) Accelerator-Based Fusion With an Artificially Structured Boundary that Produces a Purely Magnetic Periodic Field

by Luke Claycomb
103 (Poster session) X-ray Spot Size Improvements and Challenges in the 7 MeV S-Band LINAC for NDT *by Devon Fischer*
97 (Poster session) Accelerator-Based Fusion with Reduced Electronic Stopping Made Possible by an Artificially Structured Boundary *by Carlos Ordonez*

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Wednesday at 2:30 PM in Quarter

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Wednesday at 2:30 PM in Pioneer IV

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238 Exploration of the combined effects of displacement damage and total ionizing dose degradation in the LM741 operational amplifier using Si ion and electron irradiation *by Joshua Michael Young*
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PR-AMP-02: Atomic & Molecular Processes in Radiobiology and Chemistry

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168 (Poster session) Sensitization effects of In-Vitro Breast Epithelial cells to Proton Irradiation by PEG-coated Gold Nanoparticles *by Nichole Libby*
170 (Poster session) The Radiosensitization Effect of Pegylated Gold Nanoparticles in Prostate Carcinoma Cells with Proton Irradiation *by Tristan Gaddis*
135 Dissociative Electron Attachment to Biomolecular Systems *by Sylwia Ptasinska*
214 Towards the Ionizing Radiation-Induced Bond Dissociation Mechanism in Guanine and DNA Fragmentation: A Density Functional Theory Simulation *by Santosh KC*
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82 Nanopatterning 2D semiconducting layers for large-scale photon harvesting and nanoelectronics *by Maria Caterina Giordano*
181 Radiation defect dynamics in semiconductors *by S. O. Kucheyev*
278 Uncovering Radiation Stability Regimes in Nanoengineered Tungsten Alloys through In Situ Ion Irradiation Experiments *by Jason R. Trelewicz*
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Thursday at 10:15 AM in Pioneer IV

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66 Response of defective $KTaO_3$ to inelastic interactions of ions *by Gihan Velisa*
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Posters

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AA-IBTM-02 # 164 Comparison of PIXE and XRF Results on Ancient Egyptian Bronze Artifacts *by Benjamin Lukk*
AA-IBTM-03 # 193 Exploring new methods to monitor proton beam damage for sequential elemental and molecular imaging on a single tissue section *by Catia D S Costa*
AA-IBTM-04 # 171 Investigation of the stopping power of energetic ions in liquid water *by Jorden Matty*
AA-IBTM-05 # 81 Improvement of light element analysis by external proton beam *by Patrick Kirscht*
AA-IBTM-05 # 91 Simulation of MeV ion scattering including coincidence techniques for light ion depth profiling *by Hans C Hofsaess*
AA-IBTM-05 # 111 Hydrogen detection using low and medium energy ions *by Lyudmila V Goncharova*
AA-IBTM-05 # 155 Ion Beam Analysis of a Cerium(III) Tris[bis(trimethylsilyl)amido] Phosphine Oxide Crystal *by Stewart Bragg Younger-Mertz*
AA-NBAT-01 # 243 The Liquids Reflectometer at the Spallation Neutron Source *by Jim Browning*
AA-NBAT-01 # 244 Time-resolved neutron reflectometry study of Li-mediated electrochemical nitrogen reduction *by Mathieu Doucet*
AC-TD-01 # 97 Accelerator-Based Fusion with Reduced Electronic Stopping Made Possible by an Artificially Structured Boundary *by Carlos Ordonez*
AC-TD-01 # 103 X-ray Spot Size Improvements and Challenges in the 7 MeV S-Band LINAC for NDT *by Devon Fischer*
AC-TD-01 # 138 Accelerator-Based Fusion With an Artificially Structured Boundary that Produces a Purely Magnetic Periodic Field *by Luke Claycomb*
AC-TD-01 # 167 Accelerator-Based Fusion Fuel Options for Using an Artificially Structured Boundary *by Kelly Wood*
AC-TD-01 # 259 Designing Accelerator-Driven Experiments For Accelerator-Driven Reactors *by Mary Anne C Cummings*

AC-TD-02 # 260 Innovative Magnetron Power Sources for Superconducting Accelerators *by Mary Anne C Cummings*
AP-MA-06 # 131 Simulation and Measurements for the 11B(p,α)2α Reaction Using a Multi-Detector Setup *by Jacob Baxley*
AP-SD-01 # 58 Detection of shielded special nuclear materials and other contraband by using portable, high-flux DD and DT neutron generators *by Xianfei Wen*
AP-SD-01 # 267 Light-Ion Production of Gold Radioisotopes from Natural Platinum Targets *by John Wilkinson*
AP-SD-02 # 178 Time-Resolved Digital Data Analysis for Neutron Active Interrogation *by Abbas Jinia*
AR-ISM-02 # 47 Optical properties of SiGe nanocrystals in SiO_2 produced by ion implantation *by Matheus C. Adam*
AR-ISM-02 # 71 The Impact of SHI Irradiation on the Low-Temperature Dielectric Phase Transition in $K_2Bi_4Ti_4WO_{18}$ *by Vipul Kumar Sharma*
AR-ISM-06 # 44 Doping of 2D materials by Ultra-low Energy Ion Implantation *by Felix Junge*
AR-ISM-06 # 263 Effect of Nitrogen Ion Incorporation into Indium Antimonide Nanoribbons *by Alexander Sten*
AR-RE-04 # 110 XPS measurements of organic molecule degradation after exposure to MeV ion irradiation *by John Derek Demaree*
AR-RE-07 # 31 in-situ Defect Characterization of Ion Irradiated Materials with Positrons *by Thai hang Chung*
AR-RE-08 # 10 Band gap modification of CVD grown few-layer MoS2 under Swift heavy ion irradiation *by Mayur Khan*
AR-RE-08 # 64 Anomalous phase transformation in swift heavy ion-irradiated δ-$Sc_4Hf_3O_{12}$ *by Masanari Iwasaki*
PR-AMP-02 # 93 First Experimental Verification of Einstein's $E=mc^2$ by Cockcroft and Walton: Re-visited *by Ajay Sharma*
PR-AMP-02 # 168 Sensitization effects of In-Vitro Breast Epithelial cells to Proton Irradiation by PEG-coated Gold Nanoparticles *by Nichole Libby*
PR-AMP-02 # 170 The Radiosensitization Effect of Pegylated Gold Nanoparticles in Prostate Carcinoma Cells with Proton Irradiation *by Tristan Gaddis*
SN-STDS-01 # 216 3 MeV Pelletron Facility at Sandia National Laboratories *by George R Burns*
SN-STDS-02 # 258 Capability of 6MV Tandem Accelerator Facility at Sandia National Laboratories *by Armin de Vera*

CAARI-SNEAP Abstracts

Abstract 237 MON-PS-AP-01-1 Plenary Talk - Monday 8:45 AM - Kincaid

FLASH: a new paradigm in cancer radiation therapy and novel technology for its clinical translation

Bill W. Loo

Department of Radiation Oncology- Division of Radiation Therapy, Stanford School of Medicine- Cancer Center, Stanford California, United States

Achieving a high therapeutic index, or the balance between cancer eradication and collateral injury to normal tissues, is the critical challenge of all cancer therapies. The major gains in therapeutic index of cancer radiation therapy over the last few decades have come through highly conformal shaping of radiation doses to maximize tumor dose while minimizing incidental normal tissue dose, combined with precise image-guided delivery. FLASH represents a new opportunity for improved therapeutic index through a differential response between normal tissues and tumors to ultra-rapid (sub-second) delivery of radiation compared to conventional delivery (over minutes). This presentation will review recent preclinical data on FLASH radiation biology and address some hypotheses about the underlying mechanisms that remain to be elucidated. Meanwhile, there are substantial technological barriers to clinical implementation of FLASH. In particular, current approaches to delivering radiation much more rapidly compromise the dose conformity that has been a central advance in radiation therapy. This presentation will provide an overview of novel technologies toward delivering highly conformal FLASH, including a new class of linear accelerator and RF power sources as well as all electronic radiation intensity modulation approaches.

Abstract 51 MON-AA-IBTM-01-1 Invited Talk - Monday 10:00 AM - Kincaid (Hybrid)

Optimization of MeV ToF SIMS in the low primary ion beam energy mode for the analysis of inorganic materials

Marko Barac[1,3], Marko Brajkovic[1], Zdravko Siketic[1], Janez Kovac[2], Iva Bogdanovic Radovic[1]

[(1)]Division of Experimental Physics, Ruder Boskovic Institute, Zagreb, Croatia
[(2)]Department of Surface Engineering, Jozef Stefan Institute, Ljubljana, Slovenia
[(3)]Jozef Stefan International Postgraduate School, Ljubljana, Slovenia

MeV SIMS is a fairly new ion beam analysis (IBA) surface-sensitive technique that has proven to be very efficient for the analysis and imaging of organic materials in various fields such as forensics (fingerprints and inks), cultural heritage (paints), biology (plants and tissues), etc. The technique is based on the excitation of secondary molecules by primary ions having energies in the MeV region. Due to the interaction mechanism of the MeV ions with the material (mainly with the electronic system), MeV SIMS is suitable only for the analysis of organic samples and is inefficient for the analysis of inorganic materials that require direct energy transfer to secondary ions via nuclear scattering.

In the present work, MeV SIMS capabilities are explored in the energy range where nuclear and electronic stopping are equally occurring, with the assumption that this is a prerequisite for the desorption of both inorganic and organic ions. The technique is thus named low-energy MEV SIMS (LE MeV SIMS). For the investigation of secondary ion yield of various inorganic matrices and an amino acid leucine target, copper primary ions with varying energies of several hundred keV were employed. It is shown that a Cu^{2+} beam of around 500 keV focused to micrometer dimensions has the potential to desorb both organic and inorganic ions simultaneously and could possibly be used for hybrid material analysis and 2D imaging. This is demonstrated on a hybrid sample consisting of chromium partially coated with the amino acid leucine. When performing 2D imaging of such a sample with a 555 keV Cu^{2+} beam, the yield of leucine remains sufficiently high relative to the MeV region, while the yield of chromium rises to a level of satisfactory efficiency, thus largely reducing the contrast between the two regions. The possibility of MeV SIMS depth profiling of inorganic materials is also explored using a 555 keV Cu^{2+} beam while etching the surface with 1 keV Ar^{+} ions. This is demonstrated on a dual-layer sample consisting of a 50 nm Cr layer deposited on a 150 nm ITO glass. The obtained depth profiles are compared to keV SIMS depth profiles of the same target and corroborated by AFM and TOF-ERDA analysis. The results show the potential of low-

energy MeV SIMS depth profiling in accelerator facilities equipped with a MeV SIMS setup and a fairly simple sputtering source.

Abstract 249 MON-AA-IBTM-01-2

Contributed Talk - Monday 10:00 AM - Kincaid (Hybrid)

Probing the Ion Migration in 3-D Triple-Cation Perovskite Solar Cells via Rutherford Backscattering Spectrometry

Mritunjaya Parashar[1], Mohin Sharma[1], Darshpreet Kaur Saini[1], Todd A. Byers[1], Ahmad R. Kirmani[2], Joseph M. Luther[2], Ian R. Sellers[3], Bibhudutta Rout[1]

[(1)]Department of Physics, Ion Beam Laboratory, University of North Texas, Denton, Texas, United States
[(2)]National Renewable Energy Laboratory , (NREL), Golden, Colorado, United States
[(3)]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, 440 W. Brooks St., Norman, Oklahoma, United States

In recent years, mixed organic-inorganic halide perovskites (OIHPs) have been a center of interest due to their astounding capability for solar energy harvesting. As a result of continuous effort from the photovoltaic community, 3-D triple-cation perovskite photoabsorber ($Cs_{0.05}(MA_{0.17}FA_{0.83})_{0.95}Pb(I_{0.83}Br_{0.17})_3$) has emerged as one of the most promising compositions in terms of stability and power conversion efficiency (PCE) for perovskite solar cells (PSCs). However, the role of ionic motions of the various cations/anions in OIHPs is still not fully explored and it is considered one of the possible reasons for the device degradation and hysteresis in the PSCs. Furthermore, as PSCs are now promising candidates for space photovoltaic applications, it becomes very important to study the role of radiation-induced damage in PSCs. Ion beam techniques such as Rutherford backscattering spectrometry (RBS) can be a powerful tool to probe the elemental depth profile of multilayer PSCs as well as to study the inter-diffusion of various ionic species of OIHPs between the different interfaces. In the present work, we have used 2 MeV He^+ beam to probe the evidence of ion migration between different interfaces in a state-of-the-art PSC having a device architecture as: Glass/ ITO/ SnO_2/ $Cs_{0.05}(MA_{0.17}FA_{0.83})_{0.95}Pb(I_{0.83}Br_{0.17})_3$/ Spiro-OMeTAD/$MoO_2$/ Au. We will be presenting elemental compositional depth profiles as well as any beam-induced diffusion of the elements.

Abstract 248 MON-AA-IBTM-01-3

Contributed Talk - Monday 10:00 AM - Kincaid (Hybrid)

Trace-elemental analysis of herbal plant leaves using Particle Induced X-ray Emission

Darshpreet Kaur Saini, Todd A. Byers, Cory Nook, Mohin Sharma, Mritunjaya Parashar, Gary A. Glass, Bibhudutta Rout

Ion Beam Laboratory, Department of Physics, University of North Texas, Denton, Texas, United States

Tulsi (Ocimum Sanctum), Hibiscus (Hibiscus Rosa-Sinensis), and Neem (Azadirachta Indica) are known to be of great value in the field of medicine. Due to the many health benefits, these leaves offer, the elemental concentrations levels have been investigated in these types of leaves in past decades. Our study is focused not only on the quantitative estimation of the concentration of both major and minor elements but also on the individual elemental mapping and correlation between those elements at different spatial locations. The solid sample of each leaf was used for micro-PIXE and the powdered sample for the broad-beam PIXE analysis. We obtained the elements in low concentrations and correlated some of the major elements for interesting areas. Our study also showed the distribution of elements in fresh and aged leaves of the same sample showing the increase in chlorine concentration in aged leaves thus turning them yellow. The relation between calcium and potassium yielded interesting arguments along with many trace elements playing a vital role in making these leaves fit for pharmaceutical use. We will be presenting experimental results involving the elemental maps, concentrations, and correlation between major and minor elements at different spatial locations.

Abstract 102 MON-AC-AF-01-1 Invited Talk - Monday 10:00 AM - Pioneer III

Beam Commissioning and Setup for the First User Experiments at FRIB's Advanced Rare Isotope Separator

Kei Fukushima, Marc Hausmann, Peter Ostroumov, Mauricio Portillo, Mathias Steiner, Oleg Tarasov, Tong Zhang

Facility for Rare Isotope Beams, Michigan State University, East Lansing Michigan, United States

The Facility for Rare Isotope Beams (FRIB) includes a superconducting driver accelerator designed for up to 400kW of 200MeV/u heavy ion beam and the Advanced Rare Isotope Separator (ARIS). ARIS collects and purifies the rare isotope fragments of interest for experiments in nuclear physics, nuclear astrophysics, fundamental symmetries, etc. ARIS consists of a vertical pre-separator and a horizontal separator section and supports various operational modes including momentum compression using a wedge shape degrader. Beam commissioning of ARIS started in early 2022, and the first cycle of user experiments with a 1kW primary beam was completed in August. We performed the beam tuning with on-the-fly numerical simulations and demonstrated particle identification of fragments for users. Results and findings obtained from commissioning and early operation will be reported.

Abstract 125 MON-AC-AF-01-2 Invited Talk - Monday 10:00 AM - Pioneer III

Radiation Effects Facility at the Texas A&M University Cyclotron Institute

C. E. Parker, H. L. Clark, G. Avila, V. Horvat, B. Hyman, M. Kennas, G. J. Kim, H. I. Park, R. Rinderknecht, B. T. Roeder, G. Tabacaru

Cyclotron Institute, Texas A&M University, College Station TX, United States

The Radiation Effects Facility housed at the Texas A&M University Cyclotron Institute has provided a convenient and low-cost solution to commercial, governmental, and educational agencies in need of studying, testing, and emulating the effects of ionizing radiation on a wide variety of electronic systems for nearly 30 years. Two different cyclotrons provide either heavy ions or protons on dedicated beam lines that contain diagnostic equipment for beam quality and dosimetry. From the K500 Superconducting Cyclotron, three beam energy series are available: 15 MeV/nucleon (He, N, Ne, Ar, Cu, Kr, Ag, Xe, Pr, Ho, Ta, Au), 25 MeV/nucleon (He, N, Ne, Ar, Kr, Ag, Xe),and 40 MeV/nucleon (N, Ne, Ar, Kr). From the K150 (88-in) Cyclotron, 15 MeV/u nucleon (He, N, Ne, Ar, V, Cu, Kr) and protons in tunable energies from 6 - 45 MeV are available.

This talk will present an overview of the Radiation Effects Facility, as well as the shared footprint with the Cyclotron Institute. The talk will briefly touch on educational opportunities at the facility in radiation effects through the NASA co-sponsored Single-Event Effects bootcamp and the Master's degree program in Physics with an emphasis on radiation effects.

Abstract 234 MON-AC-AF-01-3 Contributed Talk - Monday 10:00 AM - Pioneer III

The European Ion Beam Centers Network RADIATE

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Transnational access to research infrastructures plays a vital role in the European research landscape, enabling scientist from all over the world to travel and perform experiments at European facilities. Following former EU project, i.e., AIM, SPIRIT and ITS LEIF, in the Horizon 2020 project RADIATE, Research and Development with Ion Beams - Advancing

Technology in Europe, transnational access to 14 ion beam centers is provided free of charge in the period of 2019 to mid of 2023. Important aims of the project are to further increase the visibility and the awareness of ion beam facilities and to create a lively web portal as a platform for information on ion beam research in Europe [1].

A further important objective of RADIATE is to achieve long-term sustainability of the proposed actions and thereby to transform the national ion beam centers to a coherent and well aligned network of ion beam facilities sharing one common mission for providing researchers excellent capabilities to perform their research. One important step in this direction has already been taken by opening RADIATE for other European ion beam centers as associate partners. In this larger context, RADIATE has established itself as the network of European ion beam centers and joined the "network of networks" ARIE, Analytical Research Infrastructures in Europe (2)ARIE represent now more than 120 research infrastructures providing access to photon, laser, ion, proton, high magnetic field, neutron, and electron facilities. Two joint position papers addressing the five Horizon Europe missions and viral and microbial threats have already been published [3] and joint proposals were submitted and are planned.

Future activities will concentrate on further strengthening the RADIATE network of ion beam facilities and on participating in future European transnational access calls.

[1] https://www.ionbeamcenters.eu

[2] https://arie-eu.org

[3] Analytical Research Infrastructures in Europe: A key resource for the five Horizon Europe Missions,

Analytical Research Infrastructures in Europe: Viral and microbial threats

Abstract 225 MON-AC-AF-01-4 Invited Talk - Monday 10:00 AM - Pioneer III

Workforce training in accelerator science and engineering provided by the US Particle Accelerator School and DOE Traineeships

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Effective workforce education programs in Accelerator Science and Engineering (AS&E) are key to maintaining healthy accelerator facilities supporting discovery science and high-technology applications. A broad spectrum of projects for new and upgraded facilities have created a healthy market for skilled AS&E jobs in national laboratories, universities, industry, medicine, and national security. Labs are encountering difficulties filling positions in some key specializations. Here we review the role of the US Particle Accelerator School (USPAS) and DOE Traineeships in providing graduate-level AS&E workforce training in the USA. We overview present training opportunities provided by these programs, how they are evolving with changes in the field, and potential improvements to help improve recruiting and meet future demand.

Abstract 253 MON-AP-IA-01-1 Invited Talk - Monday 10:00 AM - Quarter

Compensated Neutron Logging Tool Using nGen® D-D Neutron Generator for Am-Be Replacement

Brian Jurczyk, Robert Stubbers, Darren Alman

Starfire Industries LLC, CHAMPAIGN Illinois, United States

^{241}Am-Be (α,n) radiochemical neutron sources are used extensively in both: (1) the oil/gas industry for new and existing well exploration and evaluation, and (2) non-oil/gas industries for groundwater, mining, geotechnical, environmental, research, and energy applications. Radiochemical sources pose risks with respect to intentional or accidental diversion and/or use as a radiological dispersal device, as outlined by the US Department of Energy (see LLNL-TR-679101 report) and data from the IAEA and other governing bodies. Am-Be's >400-yr half-life and prevalence with small logging firms lacking security make finding a viable alternative neutron source to encourage industry transition and radionuclide source removal a priority.

In a compensated neutron logging (CNL) tool, an Am-Be source is spaced some distance from a pair of neutron detectors - one nearer and one farther away. The porosity of the formation is determined from the ratio of the count rates from neutrons scattering from the formation back to the near and far detectors. Neutrons from the Am-Be source have a range of energies up to 11 MeV. The higher energy neutrons penetrate deeper into the formation and may more rarely return to the detectors, while the slower population may not make it into the formation, contributing to the background signal instead.

With support from the Small Business Innovative Research program, Starfire Industries developed the "end-target" nGen®-100 D-D neutron generator for wireline logging applications. At the 2018 CAARI conference, Starfire Industries LLC presented Monte Carlo particle transport simulations showing a grounded "end-target" neutron generation emitting monoenergetic 2.5 MeV D-D neutrons could active similar statistics as a conventional Am-Be CNL tool with modified detector configuration, shielding and spacing layout. Due to the higher sensitivity of the D-D spectrum, it is possible to achieve comparable porosity statistics as a 16 Ci Am-Be source ($3.5x10^7$ n/s) used in some CNL tools with a $1.0x10^7$ n/s D-D source.

In this paper, we will present experimental data from "sandbox" tests with sand, pea gravel, crushed stone and water using the 1-11/16" nGen®-100 mated with a near/far detector array. The "sandbox" units are constructed from 330 Gallon 48"x40"x53" intermediate bulk containers modified with a central 2.5" steel pipe and filled with materials either fully wet or partially dry. The detector arrays are made using the RDT Domino® with a 30% thermal neutron capture efficiency and stacked into linear, directional arrays to fit within the 1-11/16" diameter. Detector counting data and near/far ratio will be shown for several different "sandbox" configurations, along with information on porosity, density and fill. The QL40-NGEN-CNL basic wireline neutron porosity tool with Mt. Sopris Instruments and the Open Platform for Advanced Logging will be discussed.

Abstract 205 MON-AP-IA-01-2 Invited Talk - Monday 10:00 AM - Quarter

Finding hydrocarbons with neutrons: The physics and technology of neutron-induced gamma-ray spectroscopy in the oil patch and beyond

Richard Radtke, Jani Reijonen, Frederic Gicquel

Houston Formation Evaluation, Schlumberger, Sugar Land TX, United States

The increasing complexity of today's hydrocarbon reservoirs demands an accurate understanding of formation composition and mineralogy. This is particularly true for unconventional reservoirs, in which quantification of both mineralogy and organic carbon is critical for resource evaluation. Neutron-induced gamma-ray spectroscopy is a technique that is especially well suited to providing this information. In this talk, we will explain the basic physics underlying this technique and describe its implementation in a commercial wireline geochemical logging tool.

Central to this instrument is a compact neutron generator. The generator can withstand the high temperatures and shocks present in the downhole environment while maintaining a small enough form factor to fit inside boreholes and completions with diameters as narrow as 5.5 in. The 14-MeV neutrons are produced from the deuterium-tritium reaction, which enables the production of both capture and inelastic gamma rays from various elements of interest. These reactions provide complementary information on the formation matrix and fluids within. Fast turn-on and turn-off of the neutron pulse allows a complex, nested pulse sequence, which is used to optimize the acquisition of capture and inelastic gamma-ray spectra as well as associated measurements such as the thermal neutron capture cross section.

The success of this technique has inspired its adoption in the arena of planetary exploration. Collaborative work with NASA is underway to use similar instruments to probe the compositions of Saturn's moon Titan in the Dragonfly mission as well as water-ice deposits on the Earth's moon. Some of the challenges related to modifying the neutron generator for space applications will be discussed.

Abstract 173 MON-AP-IA-01-3 Contributed Talk - Monday 10:00 AM - Quarter

Effect of Hydrogen gas on the field emission properties of carbon nanotubes film

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For an ion source application, we studied field emission properties of carbon nanotubes film (CNTs) under hydrogen pressures from 10^{-3} to 10^{-6} Torr. We tested CNTs using a plane-plane system with an electric field from 200 to 1000 $V.mm^{-1}$. Various parameters have been modified such as the gas exposure time, the pressure and the current mode (pulsed or continuous). Measured results show that the collected current always decreases in the presence of hydrogen with maximum a divide by 10, which induces work functions have been affected by hydrogen. Pulsed emission makes it possible to reduce this phenomenon. After delivery to atmospheric pressure, the current return to the initial value, which implies that no structural modification of the CNTs has taken place. We put forward the hypothesis of a phenomenon of storage and degassing of hydrogen by the CNTs.

Abstract 239 MON-AR-NST-01-1 Invited Talk - Monday 10:00 AM - Arabian

Focused Ion Beam Capabilities for Solid-State Color Center Formation at Sandia's Ion Beam Laboratory

Michael Titze

Sandia National Laboratories, Albuquerque NM, United States

In this presentation I will provide an overview of the focused ion beam implantation capability at Sandia's Ion Beam Laboratory (IBL). The IBL houses seven operational ion accelerators. Six of these accelerators are equipped with focused ion beam (FIB) end-stations, enabling spot sizes on target in a range from < 1 nm up to 1 μm, for spatially deterministic placement of single or few ions.

Applications for focused ion implantation range from radiation effects testing in semiconductors where ions are used to generate displacement damage [1] requiring MeV energy ions, the formation of color centers in a variety of solid-state host materials [2] requiring low energy from 10's keV to 200 keV ions, and the use of ion beams to simulate dark matter interactions [3].

Here we will concentrate on the formation of color centers using low energy FIB implantation. These FIB systems have targeting resolution < 50 nm, allowing implantation into photonic structures, making them suited for quantum optics applications. To tune the optical properties of color centers, different ions can be used by utilizing a ExB FIB in combination with a liquid metal alloy ion source (LMAIS) (4)The mass resolution of ExB FIB is sufficient to implant isotopically pure ions, enabling tuning of the hyperfine structure. The resulting color centers are promising candidates as hosts for quantum information science in solid state systems since single photon emitters can be densely integrated in a CMOS compatible material system. However, fabrication of color centers is challenging and requires tradeoffs between deterministic placement, low damage introduction to minimize unintentional defects in the surrounding lattice, as well as tuning of the optical properties of the color center. Additionally, the typically low yield of implanted ions to optically active color centers is a challenge for deterministic creation of single photon emitters, requiring the use of in-situ techniques to confirm implantation and creation of an optically active defect. We address these challenges through the development of counted single ion implantation which can reduce the error in producing single defect centers by 7 times combined with in-situ photoluminescence to ensure optically active defects.

Acknowledgement:

SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525

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Abstract 228 MON-AR-NST-01-2 Invited Talk - Monday 10:00 AM - Arabian

Fabrication of Novel Ion Sources for Nanoimplantation

Aaron M. Katzenmeyer[1], Michael Titze[1], Yongqiang Wang[2], Barney Doyle[1], Edward Bielejec[1]

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Solid-state quantum structures offer a route to integrated systems that could interface to CMOS circuitry and exploit some of the associated parallel fabrication schemes. However, great demands are placed on the introduction of defects into a host material. Qubits and color centers require a defect be created within a nanoscopic volume, down to the limit of a single isolated defect, for integration and optimized coherence time. Demonstrations to-date have often relied on serendipitously finding suitable structures which is prohibitively time consuming. To address integration and purity needs, nanoimplantation in a FIB tool is a viable solution but requires novel sources for elements of interest. Here we will present our recent work fabricating challenging nanoimplantation sources (e.g., of atomic nitrogen, magnesium, tin, and lead).

The nanoimplanters we use are designed to operate with liquid metal alloy ion sources. These enable melting of a eutectic through modest Joule heating of a tungsten hairpin. After high bias extraction from the melt, ions of the desired element, isotope, and charge state are selected using a Wien (ExB) filter. Adjustable acceleration energy facilitates achieving a particular implant depth. Counting techniques can be employed to control the number of implanted ions.

The sources themselves are not commercially available, though bare tip assemblies are offered by manufacturers. A common type is comprised of metal contacts embedded in a ceramic. A tungsten hairpin is mounted to the posts for resistive heating. A coil shaped piece of tungsten wire is joined to the hairpin to form a reservoir for the source material. A sharpened piece of tungsten wire is joined to the hairpin projecting away from the reservoir for field ionization. In most cases we use such bare tip assemblies and produce sources in our custom-built source preparation unit which has the following capabilities: high vacuum to low vacuum N_2 environment; resistive heating of the tip assembly hairpin; resistive heating of a moveable ceramic boat for immersing the tungsten hairpin into the molten alloy; high bias voltage application between the tip and a moveable Faraday cup for emission characterization. Approximately 1/3 of the elements of the periodic table can be incorporated into sources this way using bulk pieces of arc-melted alloy loaded into the ceramic boat. Substantial difficulties arise if there is no suitable bulk alloy, the element has high vapor pressure at relevant temperatures, or the alloy does not wet tungsten.

For atomic nitrogen, we have yet to identify any suitable bulk alloy and while we have demonstrated the ability to strike a localized plasma in the source preparation unit by introducing nitrogen gas through a capillary, the nanoimplanters currently have no provision to implement this. Instead, we developed a process using AuSn foil heavily implanted with high energy nitrogen ions up to the saturation limit. This enabled the first atomic nitrogen ion source derived from a liquid metal alloy. We show the source emits both singly and doubly ionized atomic nitrogen ions. Limitations of this source include operation time, currently limited to lifetimes of < 500 μA·hr nitrogen emission and fabrication difficulties as this requires the delicate loading of the reservoir. For magnesium, we experienced problems associated with oxidation of the bulk starting material and high vapor pressure for a previously reported route employing a GaMg alloy as well as several other binary Mg alloys. We instead developed a AuSi-based eutectic that simplifies preparation and enables Mg implants for GaN devices. SnPb sources are useful for forming Sn and Pb vacancy complexes in diamond and have an ideal low temperature alloy in conventional SnPb solder. However solder does not wet commercially available tip assemblies typically comprised of tungsten. We present a process using Fe-containing alloy wire for fabricating custom tip assemblies. The material is easily wet by SnPb, manipulated, welded, and electrochemically etched. We have demonstrated reliable operation of this Fe alloy wire source with spot sizes < 40 nm and long (typically ~1000-2000 μA·hr) lifetimes. Consolidating resistor and reservoir functions simplifies the fabrication process and may be used to overcome limitations in the nanoimplanter source power supplies.

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Abstract 119 MON-AR-NST-01-3 Invited Talk - Monday 10:00 AM - Arabian

Creation of Deterministic Single Photon Emitters by Focused Ion Beam and In-situ Photoluminescence

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Focused ion beam (FIB), where a high energy ion beam knocks out one or few atoms in a solid-state material and thereby creating a defect center, is one of the preferred methods to create a deterministic single photon source (SPS) due to the nanometer spatial resolution. However the conversion yield for creating single defects, governed by Poisson distribution, that can be a SPS is <10%. By performing repeated low ion number implantation at predetermined locations on silicon carbide and checking for photoluminescence after each round of implantation, we create an array of single photon emitters with 9/16 locations exhibiting a single emitter, almost twice as many as can be created by typical ion implantation. The remaining emitters exhibit non-classical photon emission statistics corresponding to the existence of atmost two or three emitters confirmed through second-order autocorrelation. Our approach of checking the successful creation of defect centers by **in-situ** photoluminescence further advances the capability of FIB for nanophotonics applications.

Abstract 88 MON-AR-NST-01-4 Invited Talk - Monday 10:00 AM - Arabian

Long range collective interactions of rare earth ion arrays precisely implanted inside photonic resonators

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Engineering arrays of active optical centers coupled with photonic resonators to study collective interactions between light and atoms has been under intense research recently. Collective effects between atomic arrays and optical photons can coherently enhance directional absorption and emission, which enable development of strong atom photon interaction

interfaces with broad bandwidth. In this talk, I will report the observation of long range cooperative resonances of rare earth ion arrays precisely implanted into a thin-film lithium niobate micro-ring resonator fabricated on a nanophotonic chip. We observe enhanced emission of the implanted rare earth ions, induced by cavity assisted Purcell effect and array assisted cooperative resonances at cryogenic temperature. Enhanced light atom interactions can suppress random spontaneous emission and solid state nanophotonic chips ensure easy scalability, which can help to build efficient and multiplexed quantum networks.

Abstract 153 MON-PR-SP-01-1 Invited Talk - Monday 10:00 AM - Palomino

ONe Nova Nucleosynthesis Studies Using ^{31}Cl β-Delayed Proton Decay

Tamas Budner[1,2], Moshe Friedman[2,3], Christopher Wrede[1,2], Alex Brown[1,2], Jordi José[4,5], David Pérez-Loureiro[2], Lijie Sun[2,6], Jason Surbrook[1,2], Yassid Ayyad[2,7], Daniel Bardayan[8], Kyungyuk Chae[9], Alan Chen[10], Kelly Chipps[11,12], Marco Cortesi[2], Brent Glassman[1,2], Matthew Hall[8], Molly Janasik[1,2], Johnson Liang[10], Patrick O'Malley[8], Emmanuel Pollacco[13], Athanasios Psaltis[10], Jordan Stomps[1,2], Tyler Wheeler[1,2]

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Sensitivity studies have identified the rate of the ^{30}P(**p**,**γ**)^{31}S reaction as the largest remaining source of nuclear uncertainty for modeling nucleosynthesis in classical novae that involve the most massive oxygen-neon (ONe) white dwarfs. This thermonuclear rate strongly influences the predicted elemental and isotopic abundances of $\mathbf{A} \geq 30$ nuclides in ONe nova ejecta, which are relevant for constraining peak nova temperatures and identifying the origins of certain presolar grains, respectively. A previous ^{31}Cl **β**-delayed **γ** ray measurement at the National Superconducting Cyclotron Laboratory (NSCL) identified the existence of a low-energy, $\boldsymbol{\ell} = 0$ resonance that could potentially dominate the total rate; a subsequent radioactive beam experiment was conducted at NSCL to determine the proton branching ratio of this same resonance. This ^{31}Cl **β**-delayed proton decay measurement was the first dedicated science experiment using the Gaseous Detector with Germanium Tagging (GADGET) system, from which we report the weakest **β**-delayed, charged-particle emission ever measured for resonances below 400 keV. Combining this result with shell-model calculations of the **γ** decay partial width and past work on other resonances, we computed a newly constrained thermonuclear rate for ^{30}P(**p**,**γ**)^{31}S. Fully hydrodynamic simulations of classical nova explosions on a 1.35-$\mathbf{M}_\odot$ ONe white dwarf were performed using our recommended rate. Here we compare these results to astronomical observation.

This work was supported by the National Science Foundation under Grants No. PHY-1913554, No. PHY-1102511, No. PHY-1565546, PHY-2110365, No. PHY-2011890; the Department of Energy Office of Science under Award No. DE-SC0016052; the Natural Sciences and Engineering Research Council of Canada (NSERC); the Spanish MINECO Grant No. AYA2017-86274-P, the E. U. FEDER funds, the AGAUR/Generalitat de Catalunya Grant No. SGR-661/2017, the EU Horizon 2020 Grant No. 101008324 ChETEC-INFRA, the ChETEC COST Action (CA16117); and Korean NRF Grants No. 2020R1A2C1005981 and No. 2016R1A5A1013277.

Abstract 136 MON-PR-SP-01-2 Invited Talk - Monday 10:00 AM - Palomino

Experimental study of ^{19}Ne excited states relevant for classical novae using the Enge split-pole spectrograph at TUNL

Federico Portillo[1,2], Alison Laird[3], Kiana Setoodehnia[1,2], Caleb Marshall[1,2], Andrew Cooper[2,4], Sean Hunt[2,4], Richard Longland[1,2]

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The production rate of ^{18}F in classical novae is heavily determined by the ^{18}F(p,α)^{15}O reaction. Consequently, accurately determining the cross section for this reaction is of key importance to calculate the ^{18}F abundance in these environments. However, this cross section has large uncertainties at low energies, which have a fundamental nuclear physics origin: interference effects arising between broad resonances. Accurately determining the energies, spin-parities (J^{π}), and ANC (partial widths) of ^{19}Ne excited states corresponding to ^{18}F+p resonances is crucial to study these interference effects. In this talk we will present the results of a ^{20}Ne(^{3}He,α)^{19}Ne neutron pickup reaction at 21 MeV performed at the Triangle Universities Nuclear Laboratory (TUNL) using the high resolution Enge split-pole magnetic spectrograph. We will show new energy values and a new compilation for energies of excited states in ^{19}Ne ranging from 1-8 MeV. We will also present the results obtained for the J^{π} of the 6.290 (E_{CM} = -120 keV) and 6.132 MeV (E_{CM} = -278 keV) states. Finally, we will discuss how the reaction rates for the ^{18}F(p,α)^{15}O reaction are affected by these interference effects.

Abstract 130 MON-PR-SP-01-3 Invited Talk - Monday 10:00 AM - Palomino

ODeSA and the ^{18}O(α,n)^{21}Ne Reaction

Rebecca Toomey[1], Michael Febbraro[2], Richard James deBoer[3], Gwen Seymour[4], Harrison Sims[4], Steve Pain[2], August Gula[3], L Morales[3], S Aguilar[3], S Henderson[3], A Couture[5]

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From astrophysics to nuclear nonproliferation, the ^{18}O(α,n)^{21}Ne reaction holds interest for many areas of research, yet most of what is known about this reaction comes from total neutron cross section measurements taken over 50 years ago. For astrophysics, the formation of supernova carbonaceous dust is thought to originate from the inner He-rich zones of massive stars. We can study the isotopic abundances of these presolar grains to gain insight into explosive stellar nucleosynthesis. Analysis of presolar grains from the Orgueil meteorite found that ^{18}O had an isotopic enrichment of up to 98,000% over terrestrial abundance, in addition to high spatial correlation with hotspots of ^{15}N. A potential cause of this is that during explosive He-shell burning, the bulk of neutrons required for ^{15}N production are sourced from the ^{18}O(α,n)^{21}Ne reaction. Recent development of the spectrum unfolding method for neutron spectroscopy, and the newly built ODeSA detector array, allow for high resolution measurements of partial and total reaction cross sections. As such, a study of the ^{18}O(α,n)^{21}Ne reaction was conducted at the University of Notre Dame over the energy range E_{α}= 2-8 MeV using ODeSA and spectrum unfolding. In addition, secondary gamma rays were detected with 2 HPGe detectors. An overview of ODeSA and preliminary cross sections from the ^{18}O(α,n)^{21}Ne reaction will be presented.

Abstract 57 MON-PR-SP-01-4 Invited Talk - Monday 10:00 AM - Palomino

Study of states near E_x=6 MeV in ^{18}Ne for the ^{14}O(α,p)^{17}F reaction rate

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X-ray bursts are stellar events characterized by bright X-ray flashes being set up on the surface of neutron stars in a binary system that accrete hydrogenic matter from their neighboring main-sequence stars. Uncertainty in our present knowledge of the $^{14}O(\alpha,p)^{17}F$ reaction rate has a strong influence on the accuracy of numerical models predicting the light curves and nucleosynthesis observed in Type-I X-ray bursts. At temperatures lower than 1 GK, this rate is dominated by contributions from resonant states in the compound nucleus ^{18}Ne with excitation energies $E_x \sim 6$ MeV. The RESOLUT radioactive-ion beam facility at FSU was used to study ^{18}Ne states in this region using $^{17}F+p$ scattering of a radioactive ^{17}F beam in inverse kinematics. We report a combined R-matrix analysis of data from our experiment, with data from an earlier study of the same reaction that covered a broader energy range but with poorer energy resolution. We will report constraints that can be placed on the spin-parity of resonances and proton partial widths that are important for the $^{14}O(\alpha,p)^{17}F$ reaction rate. Our results suggest that available elastic scattering data may not be sufficient to uniquely constrain the 1- spin assigned to the ^{18}Ne state with $E_x = 6.15$MeV.

Abstract 158 MON-PR-SP-01-5 Contributed Talk - Monday 10:00 AM - Palomino

The CASPAR underground facility for nuclear astrophysics research, results and future directions

Daniel Robertson[1], Manoel Couder[1], Alex Dombos[1], Joachim Goerres[1], Orlando Gomez[1], Mark Hanhardt[2], Thomas Kadlecek[2], Rebecca Kelmar[1], Anna Simon-Robertson[1], Shahina Shahina[1], Frank Strieder[2], Michael Weischer[1]

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There is a profound difficulty in the push of nuclear astrophysics experiments to replicate the stellar burning conditions of stellar environments crucial to the chemical evolution of the elements. The closer accelerator based experiments approach the burning regime of interest, the lower the reaction probability becomes for the nuclei of study. With this exponential drop off in reaction cross-section the issue of background interference signals becomes more problematic in modern detection techniques. Current aboveground experiments have background interactions from cosmic ray interference typically much greater than expected reaction signatures. To illuminate this cosmic interference the CASPAR facility is located a mile underground at the Sanford Underground Research Facility, studying nuclear reactions of astrophysical interest center on (p,γ), (α,γ) and (α,n) reactions. This talk will highlight recent measurements at CASPAR and future programs under consideration.

Abstract 129 MON-SN-SSR-01-1 Contributed Talk - Monday 10:00 AM - Pioneer IV

New Developments at the Louisiana Accelerator Center

William Andrew Hollerman[1,2], Richard Greco[1,2], Benjamin Lukk[1], Gabriela Petculescu[1,2]

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Development of the Louisiana Accelerator Center (LAC) as a major research center started in the mid 1970's at the University of Louisiana at Lafayette. These developments included the acquisition of a High Voltage Engineering Corporation (HVEC) Model KN 3000 van de Graaff accelerator and the contents of machine and metrology shops from NASA. In the early 1980's, the KN accelerator was moved into a shielded vault. In 1982, a 1 MV HVEC Model JN van de Graaff accelerator system was obtained from the University of Virginia. In 1991, a National Electrostatic Corporation 1.7 MV 5SDH-2 tandem Pelletron® accelerator system became operational, paid for by two successful Louisiana Quality Support Fund (LEQSF) grants. In 2001, an ion microprobe system from Oxford Microbeams (OM) became operational, also with funding from LEQSF. In this period, the KN and JN accelerators were decommissioned and removed from LAC.

For the most part, research at LAC has focused on a variety of topics, including the development of high-energy ion beam microscopy systems and techniques, measuring trace element concentrations in environmental and biological samples, and other similar related topics.

The 5SDH-2 is currently equipped with a: 1) Source of negative ions by cesium sputtering (SNICS), Radio-frequency charge exchange source (Alphatross), and 3) Duoplasmatron. A wide variety of negative ions, with energies of 20 to 35 keV, produced by these sources are injected into the low-energy terminal of the 5SDH-2 accelerator. The analyzing magnet attached to the high-energy end of the 5SDH-2 has a mass-energy product of 300 u-MeV.

Currently, there are three high-energy transport beamlines: 1) Micro-beamline, 2) Ultra-low flux biosafety level-2 beamline, and 3) Implantation beamline. The micro-beamline is equipped with an ion pump to maintain low pressures. The entering ions entering pass through objective slits and are focused to a spot of 10 × 10 μm by means of a conventional OM quadrupole triplet lens system. To facilitate focusing of the ion beam, a microscope is located to view the target from the rear. Accelerated ions are raster scanned over the sample area using Ferrite cored deflector coils. The target chamber pressure is kept low using scroll and turbomolecular pumps. The ion beam analysis system is equipped with a solid-state surface barrier, x-ray, and two diode detectors located in the target chamber. X-ray spectrometry uses an Amptek XR-100SDD silicon drift detector, which has a resolution of 125 eV, active area of 25 mm^2, and is equipped with 12.7 μm thick beryllium window. Additionally, a Mylar foil (65 μm thick) is placed in front of the detector to stop backscattered ions. To maximize the collection efficiency, the XR-100SDD is 10 mm from the target at 135° with respect to the incoming beam. A solid-state surface barrier detector with 6.0 mm diameter collimator is used for RBS. The RBS detector is situated on the beam pipe in an acrylic holder 32 mm from the target at 135°. Two Hamamatsu S1223 silicon diodes, without their borosilicate glass windows, are used as particle detectors for direct and off-axis STIM. The present set-up allows utilization of one STIM detector at a time. A recent upgrade also included acquisition of OM data acquisition and GeoPIXE® software.

The ultra-low flux beamline allows for the irradiation of biological cells and tissues in a glove box at space radiation relevant doses under BSL-2 conditions. The implant beamline is used for high-energy ion implantation and high-flux irradiation. The implant line is equipped with a Faraday cup, an electrostatic steerer, a NEC beam profile monitor and beam collimating slits. The pumping has been upgraded from turbomolecular to cryogenic, to avoid oil contamination and achieve good vacuum conditions. The beam uniformity during irradiation is continuously monitored using the profile monitor using an oscilloscope.

In 2021, efforts were initiated to computerize the control system for the 5SDH-2 Pelletron using NEC AccelNET. This upgrade was a result of a successful $475,000 grant from LEQSF. At the present time, the control components for this upgrade are being manufactured by NEC. Installation and testing for this upgrade will take place in the very near future.

Abstract 116 MON-SN-SSR-01-2 Contributed Talk - Monday 10:00 AM - Pioneer IV

Status Report for Notre Dame's Nuclear Science Laboratory

Edward Stech

Department of Physics and Astronomy, University of Notre Dame, Notre Dame Indiana, United States

A status report for Notre Dame's Nuclear Science Lab will be presented. Updates on existing facilities improvements and additions will be included. The lab houses 3 pelletron accelerators (FN, 5U, 9S) and several beamlines have been under development over the last few years.

Abstract 95 MON-SN-SSR-01-3 Contributed Talk - Monday 10:00 AM - Pioneer IV

Laboratory Report discussing upgrades to the FN Tandem and the upgrading of the TUNL Low-Energy Nuclear Astrophysics Laboratory - Replacing the JN Van de Graaff with a new 2 MV Singletron.

Chris Westerfeldt

Triangle Universities Nuclear Laboratory, Duke University, Durham NC, United States

The Triangle Universities Nuclear Laboratory (TUNL) is a Department of Energy funded "Center of Excellence" operated by a consortium of local Universities: Duke University, North Carolina State University, UNC- Chapel Hill and North Carolina Central University. Together we operate six electrostatic accelerators on the Duke University Campus for basic research and some external applied programs. Terminal potentials range from 40 kV to 10 MV. Upgrades have been funded for improvements to the FN tandem and also to replace the 1 MV single-ended model JN machine which was manufactured by HVEC in 1957 with a new HVEE Singletron. That installation should be underway during this meeting and a detailed technical paper will be presented on this unique machine by HVEE in a CAARI session. I will also describe another funded project to build a 1 MV electron machine.

Abstract 11 MON-SN-SSR-01-4 Contributed Talk - Monday 10:00 AM - Pioneer IV

ANSTO Centre for Accelerator Science Status Report

David Garton

CAS - Accelerator Systems and Development Group, ANSTO, Lucas Heights NSW, Australia

The Centre for Accelerator Science at ANSTO operates 4 accelerators, for AMS and IBA measurements. Two of the accelerators are from NEC and were commissioned in 2016. The other two accelerators are an FN and HVEE 2MV Tandetron, which is just celebrating its 20th anniversary. This presentation will highlight issues that have been dealt with over the last few years, developments currently underway, and proposed developments for the future.

Abstract 72 MON-AC-AF-02-1 Contributed Talk - Monday 12:30 PM - Pioneer III

Developments at at the Australian National University's Heavy Ion Accelerator Facility

Peter Linardakis, Nikolai Lobanov, Stephen Battisson, Thomas Tunningley, Daniel Tempra, Thomas Kitchen, Justin Heighway, Chris Kafer, Alan Cooper

Heavy Ion Accelerator Facility, Australian National University, Canberra ACT, Australia

The Heavy Ion Accelerator Facility (HIAF) at the Australian National University is reaching a series 50-year milestones in its operation of the 14UD tandem pelletron particle accelerator. Far from fading into the dying light, the accelerator and facility are instead pushing toward the future with an array of major infrastructure initiatives and an expanded range of industry relevant applications. Major capability upgrade projects include construction of a space radiation testing beam line as a component of Australia's National Space Qualification Network (NSQN) and an upgrade of ion beam injection with an additional alpha ion source and beam analysis hardware. Fundamental systems too are undergoing upgrades, with an extensive renewal of control hardware and underlying EPICS software and a replacement of an aging radiation protection system. Perhaps the biggest indicator of the optimism at HIAF amongst the current, shared challenges of the world is the replacement of all ceramic acceleration tubes and posts within the 14UD to increase stability and restore the peak achievable voltage to its historical maximums.

Abstract 163 MON-AC-AF-02-2 Contributed Talk - Monday 12:30 PM - Pioneer III

Construction of an Electron Cyclotron Emission Imaging System

L. E. Henderson[1,2], C. A. Gagliardi[1,2], D. P. May[1], H. L. Clark[1], A. M. Pantoja[3]

[(1)]Cyclotron Institute, Texas A&M University, College Station TX, United States
[(2)]Physics Department, Texas A&M University, College Station TX, United States

[3]*Physics Department, Texas Lutheran University, Seguin TX, United States*

Progress on the design and fabrication of an electron cyclotron emission (ECE) imaging system for the Cyclotron Institute's 6.4 GHz electron cyclotron resonance ion sources (ECRIS) will be presented. As simultaneously captured and spatially-resolved ECE spectra would allow for localized measurements of electron energy and density in an ECRIS plasma, a quasi-optical heterodyne receiver array has been designed. The overall system design will be reported, including how off-the-shelf microwave components are being integrated, how microwave lenses have been designed, how metamaterials will form necessary beamsplitters, and how the operation and synchronization of the camera system will be achieved using microcontrollers and a DAQ computer. Improved simulation methodologies and results for the design of novel elements, such as the metamaterial mirrors with electronically controlled reflectivity, will also be discussed.

Abstract 270 MON-AC-AF-02-3 Contributed Talk - Monday 12:30 PM - Pioneer III

Harnessing the Full Capacity of the Shady Oaks LINAC for Isotope Production

Lin Shao, Michael Martin, Alan Davis, Murray Froikin, John Bisnar, Joseph Broderick

Denton Radiopharmaceutical Facilities, Denton Texas , United States

Linear Accelerator Facility at Denton, Texas, was based on an ion source and beam injection system previously designed for Superconducting Super Collider Project. The facility is featured by a radiofrequency plasma source that can produce a proton beam of ~30 mA, RFQ accelerator for beam preparation, and a drift tube accelerator for creating a beam of up to 40 MeV. The facility is currently under a redesign initiative for commercial isotope production. In this talk, the innovation and modification in beam focusing, cooling, pulsing switching, system control, and target configuration will be discussed. The modified drift-tube accelerator has a modular design, allowing independent or coupled acceleration to vary beam energies during continuous operation. The modification will significantly increase the isotope production rate. The talk further discussed the uniqueness of high-energy proton beams in meeting the market needs, considering the majority of commercial cyclotrons are limited to proton beam energies less than 18 MeV. The modified system can potentially reach a capacity equivalent to 3-5 times the typical 32 MeV cyclotron.

Abstract 246 MON-AC-AF-02-4 Contributed Talk - Monday 12:30 PM - Pioneer III

Ion Beam Irradiation and Analysis facilities at the University of North Texas

Bibhudutta Rout, Todd A Byers, Cory Nook, Jorden Matty, Darshpreet Kaur Saini, Aaron Richardson, Mohin Sharma, Mritunjaya Parashar, Charles Brown, Duncan L Weathers, Gary A Glass

Physics, University of North Texas, Denton TX, United States

The Ion Beam Laboratory (IBL) at UNT contains four ion accelerators with dedicated beamlines for a number of ion beam modification and analysis techniques and atomic and nuclear physics research. The four accelerators include a 3 MV NEC tandem accelerator, a 3 MV NEC single-ended accelerator, a 2.5 MV single-ended Van de Graaff accelerator, and a 200 keV Cockcroft-Walton accelerator, which allows for a wide range of ion energies from 10 keV to over 15 MeV. Some of the significant facilities include a high throughput ion beam focusing system utilizing magnetic and electrostatic magnetic quadrupole focusing lens microprobe system associated with a 3MV single-ended (NEC, 9SH) accelerator. The focusing system has an orthomorphic demagnification of ~100×100 for a working distance of 18 cm, regularly achieving an optimal spatial resolution of 0.5 μm with a beam current of 50 pA.

We will be presenting the capabilities of the various accelerator facilities along with examples of the current research activities in biomedical, environmental, and energy harvesting samples.

Abstract 274 MON-AP-MA-03-1 Invited Talk - Monday 12:30 PM - Quarter

The future of radiotherapy is charged particles: Exploiting physics and biology for precision medicine.

Michael Dean Story

Radiation Oncology, UT Southwestern Medical Center, Dallas Texas, United States

Charged particles have been used to treat cancer since 1954. The rationale for using charged particles was based upon their advantageous dose profile that maximized dose to the tumor target while minimizing dose to normal tissue organs at risk for adverse events. Subsequent determination of greater biological effects per unit dose from exposures to ions heavier than protons led to clinical trials with charged particles from He (1957) to C and Ne (1975) at the Berkeley National Laboratory before being closed down in 1992. Now, more than 10,000 patients have been treated with C ions starting in Japan, then Germany and now in a number of countries -but not in the US. This presentation will discuss the physics that underlies the enhanced biological response, enhancements in engineering that have driven costs downward and the growth in number of facilities as a result, and the lack of clinical data to capture level 1 data. Recent biological data has identified a number of mechanisms by which heavy charged particles illicit their enhanced effect. While DNA damage complexity has been the cornerstone explaining the biological response, that response is now known to include not only cellular effects but effects at the tissue and organismal level. These biological advances are now driving research and clinical trials in combinatorial therapies, limiting dose fractionations schedules to fewer and fewer fractions, and recent combinations with immunotherapy. Essentially, physics and engineering which got us to where we are today, will result in incremental increases in efficacy while biology will drive the increased efficacy and implementation of charged particle radiotherapy.

Abstract 262 MON-AP-MA-03-2 Invited Talk - Monday 12:30 PM - Quarter

Charged particle radiosensitization and radioprotection strategies: flip of a coin

Paul F. Wilson

Biological Sciences Division, Pacific Northwest National Laboratory, Richland WA, United States

Even with the impressive physical and radiobiological advantages of using charge particles for radiotherapy (RT), there remain significant opportunities to improve their clinical effectiveness through pharmacological means to both improve tumor cell radiosensitization and provide normal tissue radioprotection. Agents that accentuate cell killing following exposures to low linear energy transfer (LET) radiations (electrons or protons) are attractive candidates to pursue as intermediate LET ion radiosensitizers for hadron RT, however this translational track record is not very strong. Using tightly controlled human and rodent-derived in vitro cell culture models, my group and others have shown that the increased effectiveness for cell killing and DNA damage induction seen following bromodeoxyuridine incorporation and histone deacetylase inhibitor (HDACi) treatment prior to low LET irradiation is lost or even reversed when cells are exposed to intermediate LET carbon ions and high LET iron ions. Intermediate to high LET charged particle exposures also present a serious radiation risk to astronauts on extended space missions and our efforts to validate novel space radiation medical countermeasures (MCMs) have similarly been complicated by LET-specific and cell cycle phase-specific effects. Moreover, efforts to establish a robust and reliable panel of prognostic and diagnostic human biomarkers for monitoring astronaut radiation exposures and associated health outcomes have also been complicated by an unexpected diversity of transcriptomic responses following space-relevant modeled mixed-field exposures at the NASA Space Radiation Laboratory (NSRL) compared to constituent single ion exposures. Additional pre- clinical and translational studies are warranted in these areas.

This work was supported by the NASA Translational Research Institute for Space Health (TRISH) through Cooperative Agreement NNX16AO69A and funds from Brookhaven National Laboratory and Pacific Northwest National Laboratory LDRD grants under contract numbers DE- AC02-98CH10886 and DE-AC05-76RL01830 respectively with the U.S. Department of Energy.

Abstract 195 MON-AP-MA-03-3 Invited Talk - Monday 12:30 PM - Quarter

LET-Based Proton Planning - From Development to Clinical Implementation

Wei Liu

Radiation Oncology, Mayo Clinic, Phoenix AZ, United States

Pencil beam scanning (PBS) proton therapy provides highly conformal tumor coverage and superior tissue sparing. But it also introduces additional complexities when dealing with variable relative biologically effective (RBE) dose due to varying high linear energy transfer (LET) at the end of proton ranges. The oversimplified RBE=1.1 in standard care proton therapy has negatively impacted the efficacy of PBS. In this webinar, we will discuss the current progress on developing LET-based proton planning.

Recently we have developed a novel tool of dose-LET volume histogram (DLVH) to visualize dose, LET, and the structure volume in one plot, and performed LET-related toxicity studies in both PBS-treated prostate and head-neck populations facilitated by a concept of seed spot analysis. Based on these and other results, we have developed the LET-guided robust optimization to prospectively redistribute high LET from nearby OARs to tumors to minimize toxicity. This has been integrated into our GPU-accelerated and Monte Carlo-based in-house planning system, Shiva, for routine clinical use. Some DEMOs of this system will be given to show the clinical translation of our results.

Abstract 134 MON-AP-MA-03-4 Contributed Talk - Monday 12:30 PM - Quarter

Design and Execution of Experiments on Long Duration Irradiation of Uranyl Sulfate Solution for Mo-99 production

Sergey Chemerisov[1], Peter Tkac[2], Michael Kalensky[2], James Bailey[1], Phil Strons[1], Kevin Quigley[1], Roman Gromov[1], Andrei Patapenka[1], Anna Servis[2], Ken Wesolowski[1], Charles Jonah[1], Kurt Alford[1], David Mullins[1], Josh Hlavenka[1], Ronald Kmak[1]

[(1)]Experimental Operations and Facilities Division, Argonne National Laboratory, Lemont IL, United States
[(2)]Chemical Fuel Cycle Technology Division, Argonne National Laboratory, Lemont IL, United States

With support from NNSA Material Management and Minimization office (M3) Argonne pursues the development of technologies to establish the domestic supply of Mo-99 medical isotope. Argonne National Laboratory (Argonne) is assisting SHINE Medical Technologies, Inc. (SHINE) in performing studies on uranium and iodine speciation in a neutron-irradiated aqueous homogeneous uranyl sulfate target solution. To conduct experimental studies of uranyl sulfate solution behavior in a high radiation field Argonne has developed a neutron generating target system that allows irradiation of 50 ml of solution at the fission powers and temperature similar to the production unit. Universal neutron irradiator incorporates a high-Z converter, neutron reflector, solution capsule, temperature control systems, and catalytic hydrogen/oxygen recombiner. Interaction of high energy electron beam with high-Z converter generates a high flux of Bremsstrahlung photons inducing a photonuclear reaction in the solution target and surrounding beryllium reflector. The design of the dry well allows the placement of different samples inside high neutron flux region for future studies. In this presentation, we will discuss the experimental setup design and the results of the experiments.

Abstract 40 MON-AP-SD-01-1 Contributed Talk - Monday 12:30 PM - Palomino

High Performance Silicon Drift Detectors for synchrotron applications

Andrew Jarrett

Hitachi-Hightech Science America, Dallas Texas, United States

High performance silicon drift detectors (SDD) have been developed for accelerator and synchrotron applications. Main benefits of the new SDDs are the larger solid angle, improved efficiency at high energy and great count rate performance. Several approaches make these improvements possible:

2.0mm thick SDD have been developed and allow for better quantum efficiencies (QE) at high energy (>10KeV). 2.0mm thick SDD has a QE of 0.85 at 20KeV. While 0.5mm has a QE of 0.37 and 1.0 mm has a QE of 0.6 for 20keV, respectively.

The new multi-element detectors, four elements ME4S and seven elements ME7, have one of the most compact designs of multi-element x-ray detectors, which enables minimized dead area and a large solid angle.

The last advancement was SDD response time. Even with 2.0mm thick and 70mm^2[TE1] [AJ2] [TE3] effective area detector, an average rise time around 20ns can be achieved. Studies have shown results in improving the deadtime (DT) with the 2.0mm SDD, an output count rate of 1.9 Mcps was achieved at 2.5 Mcps input count rate with a 22% DT at 192 eV [TE4] energy resolution.

This poster will present the performance of 2.0mm SDD, including energy resolution, counting throughput, peak-to-background, XRF spectra comparison with 0.5mm and 1.0mm, spectra in PIXE system, as well as the performance of ME7

Abstract 41 MON-AP-SD-01-2 Contributed Talk - Monday 12:30 PM - Palomino

RSim: A Monte Carlo simulation application with CAD capability, Geant4 for radiation modeling, and visualizable mesh scoring

David A. Alexander[1], Jenisha Baskota[1], Makoto Asai[2]

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[(2)]Thomas Jefferson National Accelerator Facility, Newport News VA, United States

RSim, developed by Tech-X Corporation with grants from DOE and NASA, augments the well-established radiation transport model, Geant4, with user interfaces to import CAD, to easily define radiation sources and scorers to capture output, and to visualize results. With RSim, simulations are set up and run through the user interface, eliminating the need for C++ or Geant4 input commands. Additionally, RSim is integrated with CAD and offers shape healing, making it ideal for users working with complex geometries. RSim features a unique geometric biasing source capability to expedite simulation times while obtaining accurate statistics. Multiple shape and mesh scorers, such as energy deposition, dose, and flux calculation, can be calculated using RSim and visualized in 3D against the modeled geometries. The intuitive RSim interface with a rich database of materials, and multiple options for radiation source customization will be demonstrated. RSim is used by engineers to easily predict radiation effects, perform shielding calculations, and assess survivability of humans and electronics in harsh surroundings like space. In particular, RSim is being used in the current NASA Artemis moon missions to assess the safety of the crew in the Orion module.

Abstract 87 MON-AP-SD-01-3 Contributed Talk - Monday 12:30 PM - Palomino

Photofission Neutron Detection with Neural Network based Digital Pulse Processing.

Abbas Johar Jinia[1], Christopher Meert[1], Tessa Maurer[1], Shaun Clarke[1], Hun-Seok Kim[2], David Wentzloff[2], Sara Pozzi[1,3]

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Detection of prompt photofission neutrons is a strong indication of the presence of special nuclear materials. However, the high energy photons used for interrogation create a very challenging radiation environment for the detection of prompt fission signatures. These challenges include detector saturation, pulse pile-up, and a neutron background due to (**γ,Xn**) photonuclear reactions in the surrounding high-Z materials. At the University of Michigan, we have developed an active interrogation system that uses bremsstrahlung radiation produced from a 9 MeV electron linear accelerator as an ionizing source and trans-stilbene organic scintillators for fast neutron detection. A system of artificial neural networks has been developed to mitigate the effect of pulse pile-up by classifying scintillation pulses as neutrons and photons and recovering neutron and photon events from piled-up pulses. In the present work, depleted uranium targets of varying thicknesses i.e., 1.27 cm, 2.54 cm, and 3.81cm are interrogated with the bremsstrahlung radiation. Preliminary results show that the photoneutron count rate increases with the thickness of depleted uranium. This increase in the count rate is expected because with increasing mass of uranium there is an increase in the photonuclear reaction rate. We observe a difference in photoneutron light output distribution with and without the presence of depleted uranium. This difference is expected because photoneutrons from (**γ,n**) reaction have a maximum kinetic energy, which is determined by the endpoint energy of bremsstrahlung photons and Q-value of the reaction. However, photofission neutrons, emitted with a Watt energy spectrum, have energies up to 10 MeV and beyond. A difference in the slope of the photoneutron light output distribution is observed with and without the presence of depleted uranium. Photoneutrons from active background exhibit a sharp slope relative to photoneutrons from depleted uranium, thereby demonstrating the presence of prompt photofission neutrons. After information is recovered from piled-up pulses, the shape of the light output distribution remains unaffected. The pile-up recovery provides an efficiency boost of approximately 13% to the active interrogation system.

Abstract 215 MON-AR-NST-04-1 Invited Talk - Monday 12:30 PM - Arabian

In-situ observation of ion-induced nanoscale patterning on a crystalline Ge(001) surface

Denise J. Erb[1], Peco Myint[2,3], Kenneth Evans-Lutterodt[4], Karl Ludwig[3,5], Stefan Facsko[1]

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[(5)]Department of Physics, Boston University, Boston Massachusetts, United States

A plethora of self-organized nanoscale patterns emerge on surfaces which are irradiated by low-energy ion beams (1)Depending on the irradiation conditions, hexagonally ordered dot or pit patterns, checkerboard patterns, as well as periodic ripple patterns are formed spontaneously due to the non-equilibrium conditions induced by continuous ion irradiation. In-situ studies of the surface morphology can reveal the kinetics of the patterning process, yielding further insight into the dominant mechanisms and thus enabling to gain precise process control.

Here, we present a real-time in-situ Grazing Incidence Small Angle X-Ray Scattering (GISAXS) investigation of reverse epitaxy patterning in crystalline Ge(001). From characteristic features of the angular distribution of scattered X-ray intensity we deduce the significant morphological parameters of the surface, thus tracking the development of the surface morphology with time during ion irradiation.

These findings are compared with results from simulations based on a continuum equation of the local surface height. Good agreement of the simulation with both experiment and theory was only achieved when including in the continuum equation an additional term for regulating the pattern anisotropy. We then find that a continuum equation considering only diffusive effects reproduces the experimentally observed surface patterning kinetics well.

Observing the kinetics of pattern formation in the non-linear regime, we find that the temporal evolutions of characteristic length and roughness conform to power laws, their exponents agreeing with scaling laws for conserved continuum equations with four-fold symmetry. Moreover, we find that the facet angle kinetics can be described by the Austin-Rickett equation for diffusion-controlled transformation processes, corroborating our assumption of a predominantly diffusive mechanism of pattern formation.

[1] Cuerno, R. & Kim, J.-S., J Appl Phys 128, 180902 (2020).

Abstract 23 MON-AR-NST-04-2 Invited Talk - Monday 12:30 PM - Arabian

Atomistic mechanisms of nanoripple formation under tilted low energy ion irradiation

Alvaro Lopez-Cazalilla, Flyura Djurabekova, Kai Nordlund

Deapartment of Physics, University of Helsinki, Helsinki Uusimaa, Finland

Self-organized patterns on sand generated by blowing winds or on the bottom of shallow rivers generated by rapid streams have attracted a human eye by their geometric regularity whose formation mechanisms are not immediately intuitive. Surprisingly, similar phenomena driven by a self-organization process, have been observed at nanoscale after long ion irradiation under tilted incidence. The origins of this effect have been under debate for decades. Although there are many analytical theories suggested to explain the phenomenon, verification of these models would be possible only through computer simulation methods. However, short time and length scales of molecular dynamics methods limited the application of atomistic simulations in order to gain insights on the processes developed on surface that may lead to its self-organization.

Recently we have developed a new methodology by using a novel accelerated molecular dynamics methodology, we are able to simulate directly the process of the ripple formation by high fluence ion irradiation (1)Since this approach does not require the presence of a precursor or pre-assumed mechanism to trigger self-organization, it can be used for first-principles insight into the origin of the ion-induced ripple formation mechanism. Analysis of the simulation shows the exact mechanism of ripple formation to be dominated by surface atom displacement and a pile-up effect, implying also that the mechanism on the nanoscale is analogous to the macroscopic ones. We also show that the simulations correctly reproduce the experimentally observed dependence of ripple formation on incoming angle [2].

[1] A. Lopez-Cazalilla, A. Ilinov, C. Fridlund, F. Djurabekova, , and K. Nordlund, Direct observation of ion-induced self-organization and ripple propagation processes in atomistic simulations, Mater. Res. Lett. 8, 110 (2020).

[2] A. Lopez-Cazalilla, A. Ilinov, F. Djurabekova, , and K. Nordlund, Modeling of high-fluence irradiation of a-Si and Al by linearly focused Ar ions, J. Phys: Condensed Matter 31, 075302 (2019).

Abstract 25 MON-AR-NST-04-3 Invited Talk - Monday 12:30 PM - Arabian

Simulation of low energy ion-solid interactions using the binary collision approximation

Hans C Hofsaess[1,2], Felix Junge[1,2], Patrick Kirscht[1,2], Koen van Stiphout[1,2]

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The fundamental features of ion solid interaction simulations using Monte Carlo methods and the binary collision approximation are discussed. In particular we will highlight simulation of low energy ion irradiation of materials, which are relevant for sputter erosion and pattern formation at surfaces and ultra-low energy ion implantation of two-dimensional materials. For low energy collision cascades it is necessary to include simultaneous weak collisions and to chose proper

atomic binding energies, surface binding energies and cutoff energies. We will present several examples, including experimentally measured range profiles, showing the relevance of theses parameters for accurate simulation of sputter yields, crater function moments and even implantation range profiles. Simulations were done using the novel IMINTDYN program code, an upgrade based on the SDTrimSP code.

Abstract 113 MON-SN-STDS-01-1

Contributed Talk - Monday 12:30 PM - Pioneer IV

Modification of an H^- Ion Source for the Extraction of Negative and Positive Ions

Stephane Melanson, Anand George, Thomas Stewart, Morgan Dehnel

D-pace, Nelson BC, Canada

H^- is the preferred ion to use in medical cyclotrons for radioisotope production due to the ease of extraction, by way of graphite stripping foils, and to allow for variable energy extraction. However, due to the increasing popularity of certain medical radioisotopes for targeted radio-therapy, such as Astatine-211 produced by the reaction $^{209}Bi(\alpha,2n)^{211}At$, medical cyclotrons have been outfitted with electrostatic extractors to permit radioisotope production by He^{++} bombardment. Thus, an ion source that can extract H^- as well as positive ions such as He^{++} would be a useful tool for such accelerators. We present the development of a hybrid ion source based on the 15 mA TRIUMF-Licensed H^- that has been modified with an added suppression electrode to allow for the extraction of positive ions, as well as negative. This paper presents the beam current output, and emittance results at 30 kV bias voltage as well as the ion source parameter settings for the extraction for H^-, He^+, He^{++}, and H^+. Additionally, we show the dependence of the ion fractions as a function of the source parameters.

Abstract 106 MON-SN-STDS-01-2

Contributed Talk - Monday 12:30 PM - Pioneer IV

Preparation for the transfer of accelerator laboratory and installation of the new 5 MV Tandetron at RBI

Fares Boussahoul, Milko Jaksic, Zdravko Siketic, Donny Cosic, Milan Vicentijevic, Zvonko Kolar

Experimental physics department, Ruder Boskovic Institute, Zagreb Croatie (+385), Croatia

Laboratory for Ion Beam Interactions (LIBI) at the Ruder Boskovic Institute hosts the largest research facility in Croatia. It is based on two particle accelerators and nine end-stations for the performance of basic and interdisciplinary research concerning the interactions of ion beams with matter. The first accelerator is 6 MV EN Tandem Van de Graaff installed in 1962 at Rice University in Texas and moved to Croatia in 1987. The second one is a 1 MV Tandetron accelerator installed in 2004.

After 60 years of operation, the VdG accelerator voltage is limited to 4 MV because of a leak in the accelerating tube that opens when the insulating gas pressure is above 10 bars. The charging belt damage is also one of the major problems because it induces instability in the charging process translated by fluctuation in the beam current during irradiation.

A plan to replace the 6 MV VdG with a new 5 MV Tandetron started ten years ago. The new accelerator project consists of a new building and replacement of the VdG accelerator while keeping the ion sources and beamlines. The challenge to achieve the planned goals will be moving a 1MV Tandetron accelerator, 9 beam lines with end stations, and 4 ion sources efficiently and in a reasonable time.

This presentation gives an overview of the preparations, like replacing the old equipment with modern ones, optimizing the hardware configuration, and adapting the software. This includes upgrading the control system of major parts starting with accelerator control, ion sources, vacuum system monitoring, etc. Beam transport simulation using Transport PSI software to design the injection part of the new 5 MV Tandetron has been performed. In the meantime, a new 200 KV ion implanter is under construction to be transferred to the new building as well.

Abstract 59 MON-SN-STDS-01-3 Contributed Talk - Monday 12:30 PM - Pioneer IV

Conducting Self-Ion Irradiation Experiments in Candidate Core Structural Materials at the Michigan Ion Beam Laboratory

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Ion irradiation has the potential to be used as a surrogate for neutron irradiation of candidate core structural materials. To minimize composition changes during irradiation and maximize the damage rate, self-ions should be selected as an ion species used to induce radiation damage. However, simultaneous implantation with He and possibly H as transmutation surrogates will be required to reproduce the radiation environment in a reactor. A reproducible ion beam irradiation experiment requires close control of irradiation parameters and the irradiation environments, such as ion beam current, temperature, vacuum, and contamination control.

The Michigan Ion Beam Laboratory (MIBL) at the University of Michigan in Ann Arbor, Michigan, USA, is a charter laboratory of the NSUF (National Scientific User Facility) and plays a significant role in supporting the mission of the U.S. DOE Office of Nuclear Energy. MIBL houses 3 MV and 1.7 MV tandem accelerators and 400 kV single-ended accelerator. MIBL provides single, dual, and triple beam irradiation capabilities and single and dual beam in situ capabilities in a 300 kV transmission electron microscope (TEM). The lab can conduct irradiations with large beam fluences, in ultra-high vacuum chambers, and with full remote control of irradiation conditions. At MIBL, experimental conditions are controlled to within very tight specifications. This presentation will focus on the features of conducting well-controlled ion beam irradiation experiments at MIBL. A brief introduction of the control and data acquisition system will be presented. The performance and capabilities of the recently added sputter source on 3.0 MV Pelletron will be highlighted.

Abstract 22 MON-SN-STDS-01-4 Contributed Talk - Monday 12:30 PM - Pioneer IV

Uplifting ANSTO Tandem Accelerator Facilities for the Future

David Button[1], Andrew Downes[1], David Garton[1], Michael Mann[1], Nikolas Paneras[1], Emilie Pons[1,2], Matthew Rees[1]

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The Australian Nuclear Science and Technology Organisation (ANSTO), maintains and operates four tandem accelerator facilities. These consist of ANTARTES (FN) 10MV established in 1992, Sirius (NEC) 6MV established in 2015, STAR (Tandetron) 2MV established in 2004, and 1MV (NEC) Vega established in 2014. ANSTO's success in contributing to accelerator science and techniques, has necessitated the need to uplift our older facilities to meet the emerging challenges for the future.

This presentation will look at the ambitious program to uplift our ANTARES and STAR facilities, bringing the instrumentation, and controls up to a more modern standard. This talk will also discuss a new automated sample changing system currently under development for one of our IBA end-stations (PIXE, PIGE, PESA, RBS). The new sample management system aims to convert our existing multi-sample stick system, to a cassette-based system increasing capacity from 20 to 100+ samples extending unattended operation periods between sample change overs.

Abstract 177 MON-AC-TD-02-1 Invited Talk - Monday 2:30 PM - Quarter

On-chip Integrated Laser-driven Particle Accelerators

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Acceleration of particles in photonic nanostructures fabricated using semiconductor manufacturing techniques and driven by ultrafast solid state lasers is a new and promising approach to developing future generations of compact particle accelerators. Substantial progress has been made in this area in recent years, fueled by a growing international collaboration of universities, national laboratories, and companies. Performance of these micro-accelerator devices is ultimately limited by laser-induced material breakdown limits, which can be substantially higher for optically driven dielectrics than for radio-frequency metallic cavities traditionally used in modern particle accelerators, allowing for 1 to 2 order of magnitude increase in achievable accelerating fields. The lasers required for this approach are commercially available with moderate (micro-Joule class) pulse energies and repetition rates in the MHz regime. We summarize progress to date and outline potential near-term applications and offshoot technologies.

Abstract 182 MON-AC-TD-02-2 Invited Talk - Monday 2:30 PM - Quarter

Laser-ion sources for multidisciplinary research applications

Lieselotte Obst-Huebl, Kei Nakamura, Sahel Hakimi, Jianhui Bin, Stepan S. Bulanov, Axel Huebl, Qing Ji, Laura D. Geulig, Sven Steinke, Jared DeChant, Zachary Kober, Tobias M. Ostermayr, Jian-Hua Mao, Antoine M. Snijders, Eleanor A. Blakely, Thomas Schenkel, Anthony J. Gonsalves, Jean-Luc Vay, Jeroen van Tilborg, Csaba Toth, Carl B. Schroeder, Cameron G. R. Geddes, Eric Esarey

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Since their experimental demonstration around the year 2000, efficient laser-driven ion sources have gained considerable attention for their compactness and capability of delivering unique ion beam parameters. The latter include very short ion pulse lengths, low emittances, high particle numbers per pulse with multiple ion species, including heavier ions, being generated in a single laser-target interaction. These source parameters render laser-ion sources attractive for various applications in multidisciplinary research and technology, e.g., in high dose-rate radiation biology, high energy density science, the study of warm dense matter, and inertial fusion energy. Some of these applications are already actively pursued in basic research settings, however, advancing laser-ion sources to be a reliable technology requires addressing several key challenges. Those include present limitations in maximum ion energies, pulse repetition rate and stability of beam parameters. This talk will discuss the current state of laser-ion sources and their applications, as well as recent research activities at the BELLA PW laser.

Funding note: The work was supported the U.S. Department of Energy Office of Science Offices of High Energy Physics and Fusion Energy Sciences, under Contract No. DE-AC02-05CH11231, and by Laboratory Directed Research and Development (LDRD) funding from Lawrence Berkeley National Laboratory provided by the Director. Work at BELLA was also supported by LaserNetUS (https://www.lasernetus.org/).

Abstract 104 MON-AC-TD-02-3 Contributed Talk - Monday 2:30 PM - Quarter

Compact Multi-beam Radio-frequency Linear Ion Accelerators

Qing Ji[1], Yuetao Hou[2], Nicholas Valverde[1,3], Meera Vikas Garud[2], Arun Persaud[1], Caroline Egan[1], Elettra Preosti[1], Zhihao Qin[1], Peter Seidl[1], Di Ni[2], Ved Gund[2], Steve Lund[3], Khurram K. Afidi[2], Amit Lal[2], Thomas Schenkel[1]

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Reducing the size, power needs and cost of accelerators opens new opportunities in mass spectrometry, ion implantation and ultimately plasma heating for fusion. We report on the development of multi-beam radio frequency (RF) linear ion accelerators that are formed from stacks of low cost wafer-based components (silicon or printed circuit boards). This implementation allows us to operate multiple ion beams in parallel for increased current densities in a multi-beamlet arrangement compared to a single beam with one large aperture. An array of 112 beamlets is formed in 4" wafers. The peak argon ion current accelerated in the 112-beamlet column to date is 0.5 mA.[1] We have accelerated ions in stacks of 32 wafers to an energy over 100 keV. The measured energy gain in each RF gap reached 6.5 keV on average, resulting in an effective acceleration gradient of 0.4 MV/m. When scaled to high beam power, with ion currents of many amperes and ion kinetic energies >1 MeV, our approach offers a low cost route to high beam power in material processing and plasma heating for potential future fusion energy applications.

*This work was funded by ARPA-E. Work at LBNL was conducted under DOE Contract DE-AC0205CH11231. Device fabrication at the Cornell Nano-Fabrication facility is supported by NSF Grant No. ECCS-1542081.

[1] Qing Ji, et al., "Beam power scale-up in micro-electromechanical systems based multi-beam ion accelerators", Rev. Sci. Instr. 92, 103301 (2021); https://doi.org/10.1063/5.0058175

Abstract 217 MON-AC-TD-02-4 Contributed Talk - Monday 2:30 PM - Quarter

Recent Activity at National Electrostatics Corp.

Stephanie Stodola, Michael Mores

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National Electrostatics Corp. (NEC), like many other businesses and researchers, was affected by the Corona Virus Pandemic and the succeeding supply chain crisis. However, NEC continued to manufacture accelerators and related components throughout the height of the pandemic. Currently, NEC expects to ship nine accelerator systems in 2023 and already has systems booked for shipment in 2024. Several of these systems incorporate technology that required significant research and design by NEC including the Positive Ion Source Mass Spectrometry (PIMS) system, a 500 kV thallium heavy ion beam probe system, and customized NEC ion source injectors and endstations that expand the functionality of existing acceleratory systems.

Abstract 61 MON-AC-TD-02-5 Contributed Talk - Monday 2:30 PM - Quarter

D-Pace UniBEam Beam Profiler Integration and High Beam Power Scan Data at the University of Washington Medical Cyclotron Facility

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The University of Washington Medical Cyclotron Facility has installed and integrated a D-Pace UniBEam optical beam profiler improving beam transport to our isotope production station. We have integrated the scanner controls and output graphics into our existing control system built on the Experimental Physics and Industrial Control System (EPICs) platform. A touchscreen display is mounted at our cyclotron operations console, running pyEpics with EPICs Extensible Display Manager (EDM) as an HMI. The original line integral graphical output has been adapted to a 2-D color map representation that is more intuitive to a beam operator. Using the original line integral plotting functions, we have scanned

our 35MeV proton beam, 22MeV deuteron beam, and 29MeV and 47MeV alpha beams. Future scans will use the new 2-D plotting on the above beams during our routine isotope research and production.

Abstract 273 MON-AC-TD-02-6 Contributed Talk - Monday 2:30 PM - Quarter

K-Modules: Capacitive energy modules for pulsed power applications

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Most linear accelerators use a pulsed power system that involves a capacitive discharge process to accelerate the ions or electrons. A Marx bank (aka capacitor bank) is most commonly used to provide this capacitive discharge. One such Marx bank was developed by Field Emission Corporation, McMinnville, OR, in the 1960s and '70s and was housed in machines designed specifically to generate X-rays up to 2.4 MeV. This class of X-ray machines came to be known as Febetrons. Approximately 25 of these "2.4 MeV Febetrons" were produced.

Flash X-ray Radiography (FXR) is the technique of capturing radiographic images of detonating objects. At Los Alamos National Laboratory (LANL)), FXR has played an important role in the Weapons Program since the Manhattan project and is critical to national security missions. LANL continues to operate 2.4 MeV Febetrons that were made five decades ago in their FXR experiments. Besides Los Alamos, the Air Force as well as aerospace companies also operate the same 2.4 MeV Febetrons. They use the Febetron output to bombard high value electronic circuit boards, such as those used in missile guidance systems, with high energy X-rays and/or intense electron beams for radiation effects testing.

These Febetrons have performed successfully for five decades. The Marx bank in these Febetrons comprises of 80 capacitive units (or modules). These modules are aging and the internal components of the modules often fail and render the whole module unusable. Replacement modules have long lead times (14-16 months). This situation poses a serious inconvenience and down time to all Febetron operations and to the very national security missions they are used for.

To fill in this deficit, our team at LANL has developed new capacitive energy modules, called "K-Modules", to replace the original ones. K-Modules were designed from first principles using SPICE models, 3D modeling software (SolidWorks) and sophisticated electrostatic simulation software (ANSYS Maxwell). Using the same factor as the original modules, K-Modules store 3x the energy, produce 1.5x output voltage and provide higher X-ray dose. The higher X-ray dose will allow us to image deeper into objects, provide higher contrast and clarity and thus sharper radiographs. It will also produce a higher flux of electrons on target for electron beam applications.

The K-Modules are serviceable, scalable, and reconfigurable, and thus may find utility in other applications such as to power X-ray and electron beam devices used to sterilize medical and healthcare products, pharmaceuticals; to irradiate and eliminate microbial contaminants in food; as well as for fracture detection in pipes in the oil and gas industry. Coupling a stack of K-Modules to an antenna will produce an intense Electro-Magnetic Pulse (EMP) and a high electric field that can be used for electromagnetic susceptibility or shielding evaluations of electronics.

The innovative design, enhancements, and versatility for potential applications won our LANL K-Module team a 2022 R&D100 Award.

Abstract 188 MON-AP-TA-01-1 Invited Talk - Monday 2:30 PM - Pioneer III

2022 First Year Pre-Orientation Program activites of the MIT Department of Nuclear Science and Engineering

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The Department of Nuclear Science & Engineering (DNSE) at MIT provides educational opportunities for undergraduate and graduate students interested in advancing the frontiers of nuclear science and engineering and in developing applications of nuclear technology for the benefit of society and the environment. Students are prepared to make contributions to the scientific fundamentals of the field; to the development and engineering of nuclear systems for energy generation, security, health care, and other applications; and to the integration of nuclear systems into society and the natural environment. The First-year Pre-orientation Program (FPOP) at MIT provides the opportunity for first year students to sample various academic departments with experiences to better facilitate decisions for major declaration. The activities of the DNSE FPOP included lectures on nuclear applications from fission and fusion energy, to advanced materials for quantum computing and energy storage/generation. In addition to providing a snapshot of potential coursework in DNSE, the FPOP activities also showcase the experimental research facilities associated with the DNSE with tours of the MIT Nuclear Reactor Lab, Plasma Science and Fusion Center, and accelerator facilities. Students are given the opportunity to participate in hands-on demonstrations of nuclear technologies. These activities include the fabrication of radiation detectors and the testing of shielding materials for neutrons and gammas. This presentation will provide information regarding these activities for the most recent year of 2022 and examples of other activities and resources the department and associated labs use for outreach and education to high school age and undergraduate students.

Abstract 63 MON-AP-TA-01-2 Invited Talk - Monday 2:30 PM - Pioneer III

Undergraduate Research at the Cyclotron Institute at Texas A&M

Lauren McIntosh

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The Texas A&M Cyclotron Institute has had an NSF funded Research Experiences for Undergraduates program since 2004. Each summer about a dozen students from across the country join us for the 10 week program. They are each imbedded in one of the research groups of the CI and given their own research project. While the main focus of their effort is their individual research project we have other activities to broaden their experience. One of those activities has been involvement in a group experiment. The group research experience allows everyone to be involved in an experiment using the accelerator. In addition to the REU program, we also have a newly founded TREND (Texas Research Expanding Nuclear Diversity) and HIPPO (Horizon-broadening Isotope Production Pipeline Opportunities) programs, which make research experiences available to more students, and participated with the REU students this year. Texas A&M undergraduates can be involved in research projects at the Cyclotron throughout the year, often for multiple years. This extended exposure enables Texas A&M students to have a learning experience that cannot be duplicated without a local accelerator. The motivation for the other undergraduate programs is to share this accelerator experience with students who did not have that opportunity at their home institution.

Abstract 269 MON-AP-TA-01-3 Invited Talk - Monday 2:30 PM - Pioneer III

Enhancing the Undergraduate Advanced Lab experience: Measuring Photons and Ions

RAHUL MEHTA

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In this paper we will discuss the experiments using ion-atom scattering and using photon measurements. Mostly Junior - senior level Physics majors were involved in these measurements of ions and photons. Ion beams from accelerators were incident on samples resulting in ion scattering and photons production in ion atom collisions. In addition, photons from radioactive sources were used in understanding of nuclear properties. Elastic and inelastic scattering of ions were recognized from conservation principles application and provided nature of collision and possible mechanism. Gamma ray and x-ray photon measurements provided data to test theories with understanding from classical and quantum mechanical picture. Some of the experiments discussed include x-ray fluorescence, Rutherford scattering, angular correlation in gamma ray emission and energy-loss of ions in matter. Recognizing uncertainties in measurements and their propagation is stressed in reaching conclusions from the measured data and calculated results. Also stressed for the detection system are the importance of energy calibration, efficiency, and other variables.

Abstract 145 MON-AP-TA-01-4 Invited Talk - Monday 2:30 PM - Pioneer III

Nuclear Labs for Undergraduates and High School Students Using a Low-Cost Gamma Spectroscopy System and Other Educational Activities at Tarleton's Nuclear Laboratory

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Since 2001, Tarleton State University's nuclear laboratory has been providing educational labs and research activities to support both undergraduates and high school students. Using Internet based multichannel analyzers, the lab supports not only Tarleton students, but undergraduates at other Texas institutions in the Texas Physics Consortium (TPC) of which Tarleton is a founding member. A discussion of the facility, various undergraduate activities, and the laboratory's K-12 outreach activities will be presented. Among those activities to be discussed is the development of a set of nuclear labs for a NaI gamma spectroscopy system that uses a computer's sound card instead of a traditional multichannel analyzer. This low-cost system (<$1500) produces lab results for pulse-height analysis and multichannel scaling comparable to more expensive systems provided labs are designed to keep count rates below 2 kHz enabling high schools and small undergraduate programs the chance to perform quality nuclear spectroscopy labs.

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Abstract 74 MON-AR-ISM-02-1 Invited Talk - Monday 2:30 PM - Kincaid (Hybrid)

Understanding of the evolution of mechanical properties of steels under irradiation: micromechanics and microstructure

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Steels are the main structural materials in current and future nuclear power plants. Radiation induced segregation/precipitation and radiation enhanced precipitation at the nanoscale impact significantly their mechanical properties. Under ion irradiation, the small thickness of the irradiated layer imposes micro-mechanical testing methods to be used such as nanoindentation and micropillar compression. The objective is to make the link between microstructural evolution and hardening owing to the combination of: atom probe tomography, transmission electron microscopy,

SEM/FIB/EBSD on one hand and nanoindentation and micropillar compression on the other hand. This correlative approach can also be used on the same materials irradiated with neutrons allowing the comparison between ion and neutron irradiation.

Abstract 240 MON-AR-ISM-02-2 Invited Talk - Monday 2:30 PM - Kincaid (Hybrid)

The key role of heavy ion irradiation in the development of ductile amorphous oxide barrier coatings for next generation nuclear power plants.

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One of the most crucial issues in the materials development for Generation IV nuclear reactors (GIVs) and for fusion nuclear power plants is to guarantee that components will retain their integrity at high temperatures, high neutron irradiation fluences, and in a highly corrosive environment. Conventional structural materials, like steels, cannot fulfil all these requirements, and hence protective coatings are emerging as a functional need in all future nuclear technologies. In this context, we developed ductile amorphous oxide coatings, deposited by Pulsed Laser Deposition (PLD) for tackling all the aforementioned issues. This new class of ceramic coatings have unique properties: high strength and ductility and a high density amorphous structure. As a matter of fact, it was recently demonstrated that 50 nm thick, defect-free films exhibit an elastoplastic response under both tensile and compressive tests at room temperature. A clear onset of plastic deformation has been observed and a yield stress as high as 4 GPa (tensile and compressive) has been measured, with a plastic deformation as high as 7 % in tension and 100 % in compression. We have also demonstrated that amorphous alumina coatings are suitable candidate for protecting steels in various corrosive environments: from salt spray test to heavy liquid metal and other fission and fusion relevant conditions. In particular, alumina coated EUROFER and 1515Ti have been tested in contact, respectively, with LiPb and Pb up to 8000 hrs, showing superior stability to any other known solution currently under evaluation. Furthermore, the amorphous oxide coatings exhibit near zero hydrogen-isotopes permeability at high temperature and under irradiation.

All the unique properties mentioned above are strictly linked to the dense amorphous structure achievable by PLD. Nevertheless, energy inputs in the form of thermal energy or irradiation can induce crystallization of the amorphous oxide coatings with a sharp degradation of its properties. Hence, it is necessary to understand the material behaviour under irradiation at various temperatures. Due to the lack and cost of neutron irradiation facilities, we rely on heavy ions with the goal to understand and develop amorphous oxide coatings stable under irradiation up to 1000 °C. We present a summary of this effort and how **in-situ** and **ex-situ** heavy ion irradiation in a wide range of temperatures, from room T up to 800 °C, is allowing us to understand the crystallization kinetics of amorphous oxide coatings and to develop materials stable at high temperatures and DPA. While waiting to get neutron irradiation data, thanks to heavy ions, we are building a rational framework for the use of this new class of protective coatings in future nuclear energy systems by correlating the evolution of mechanical and structural properties obtained in **ex-situ** studies with precise quantification of crystallization kinetics in **in-situ** ones. In sum, we show how ion irradiation is an invaluable tool for fast material development in the nuclear industry, and highlight the need for more studies on the correlation between neutron and ion irradiation.

Abstract 254 MON-AR-ISM-02-3 Invited Talk - Monday 2:30 PM - Kincaid (Hybrid)

Computing stress and strain fields resulting from exposure of materials to neutron or ion irradiation: from microscopic models to FEM of reactor components

Sergei Dudarev[1], Max Boleininger[1], Peter Derlet[2], Pui-Wai Ma[1], Daniel Mason[1], Luca Reali[1], Andrew Warwick[1]

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Multiscale modelling, aiming at delivering macroscopic predictive simulation capabilities and implemented numerically in the form of a finite element model (FEM), over the past decades has been trying to find solutions by focusing primarily on the evaluation of energies of defects, their transition energy pathways, and energy barriers controlling the rates of thermally activated processes. This physics-based approach proved to be largely detached from the notions of macroscopic elasticity, plasticity, and their FEM implementations; that latter requires computing internal and external forces acting on components, and the resulting elastic stresses and deformations.

A remarkable illustration of the fact that energies and lattice distortions generated by the defects are not directly related is provided by the example of point defects, where the divergence of the elastic self-energy at the centre of a defect shows that it is the electronic structure at the core and non-linear effects associated with short-range interatomic bonding, as opposed to purely elastic self-energy of harmonic stretching and bending of the chemical bonds that control the structure of defects and their dynamics. At the same time, the macroscopic phenomenological models often used in the context of FEM simulations suffer from the lack of transferability and hence lack genuine predictive capacity when applied to simulating the response of materials to a previously unknown operating nuclear environment, like nuclear fusion.

The recognition of the need to identify the differences and synergies in the treatment of energies and deformations generated by defects and dislocations has led to new fundamental developments in multiscale models for radiation effects in nuclear reactor components, and enabled formulating an FEM approach where defects and dislocations act as microscopic distributed sources of macroscopic elastic strain and stress fields, providing a basis for a self-consistent, as opposed to purely hierarchical, approach to the simulation of effects of irradiation on the macroscopic engineering properties of materials for reactor components.

Abstract 222 MON-AR-ISM-02-4 Contributed Talk - Monday 2:30 PM - Kincaid (Hybrid)

Development and mechanical properties of multicomponent thin films from the Cr-Hf-Mo-Ta-W system designed for harsh environments

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Compositionally complex alloys (CCAs), also known as high entropy alloys (HEAs), have gained significant attention from academia and industry in the last two decades. CCAs are multicomponent materials containing at least five elements in near-equimolar ratios. It is believed that high mixing entropy due to multi-element composition primarily leads to the stabilization of solid solution phases instead of the formation of complex intermetallic phases. After some years of study of multicomponent metallic materials, the concept was extended to multicomponent ceramics, also known as high entropy ceramics (HECs). The most studied are nitrides and carbides. In many cases, metallic and ceramic multicomponent materials present exceptional and superior properties that cannot be obtained in traditional alloys based on one or two elements, e.g., thermal stability, corrosion resistance, mechanical strength, or wear resistance. Especially interesting from the industrial point of view are very high mechanical resistance at high temperatures and exceptional irradiation resistance. Therefore, the interest should be focused on systems based on refractory elements, which present significantly better mechanical resistance at high temperatures than more commonly studied systems-based 3d-transition metals. The locally disordered chemical environment and lattice distortion in multicomponent materials result in remarkable irradiation resistance. The high chemical complexity in CCAs causes the reduction of the rate of heat dissipation during cascade collision and the decrease of the mobility of defects in the recovery of irradiated materials. Most multicomponent materials

are prepared as bulk materials. However, not less promising are thin films prepared by plasma-based techniques, mainly by magnetron sputtering.

This work focuses on the characterization of metallic and ceramic thin films from the Cr-Hf-Mo-Ta-W refractory system prepared by reactive DC magnetron sputtering from elemental segmented targets. The main aim of the project was to develop materials for high-temperature and extreme radiation environment applications. The deposited films were characterized by various techniques such as X-ray diffraction, scanning and transmission electron microscopy, and indentation. Moreover, the experimental results (lattice parameter and Young's modulus) were compared with ab-initio calculations and showed a good correlation.

The metallic film revealed a single body-centered cubic phase, coupled with a very high hardness of 17.0 GPa, and exceptionally high Young's modulus of approximately 400 GPa. The thin films deposited under nitrogen or acetylene flows showed a major multi-element face-centered cubic nitride or carbide solid solution, respectively. It confirmed that multicomponent materials, metallic or ceramic, can present a single solid solution. Most deposited films presented a columnar morphology and revealed nanometric grain size. The nitride thin films also showed promising mechanical properties such as high hardness up to 20.3 GPa and extremely high Young's modulus up to 471 GPa. The obtained results show that produced thin films can be potential candidates for high-temperature and extreme radiation environment applications.

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Abstract 245 MON-AR-ISM-02-5 Contributed Talk - Monday 2:30 PM - Kincaid (Hybrid)

Short-range order in ion-irradiated NiCoCr medium entropy alloys

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A new class of metallic materials with several principal elements named high-entropy alloys (HEAs) has been drawing considerable attention due to their superior properties, such as high strength, ductility, wear resistance, and corrosion resistance (1-2)Among them, NiCoCr medium entropy alloy seems to be a pioneer in these properties (3)Particularly interesting is its incredible radiation resistance tolerance, which, unfortunately, is still prone to debate. In our work, we study the mechanical and structural responses of single crystalline NiCoCr submitted to Ni-ion irradiation at room temperature. Obtained results show the presence of SRO (Short Range Order), which increases in density with increasing ion fluence. In addition, we noticed a significant increase in SF (Stalking Faults), in the low fluence regime. Reported structural reorientation (which most likely is Cr atoms that are favorably bonded with Ni and Co in the solid solution) was compared with recorded mechanical responses of the material. This was studied by nanoindentation. We saw a minor hardening effect in the low fluence regime, which speeds up when fluence reaches 3.5 x 10^{14} ion/cm^{-2}. Observed local lattice characteristics - the short-range order - may be responsible for the hardening phenomenon, and its explanation may shed new light on this long-lasting problem in nuclear engineering.

Literature:

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Abstract 79 MON-AR-NST-05-1 Invited Talk - Monday 2:30 PM - Arabian

Coherent X-ray Scattering as a New Tool for the Study of Ion Beam Nanopatterning

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While time-resolved x-ray scattering with a conventional non-coherent source has proven to be a powerful probe to investigate average surface evolution during ion beam nanopatterning, the coherent x-ray scattering technique of X-ray Photon Correlation Spectroscopy (XPCS) goes beyond the averaging inherent in use of a non-coherent source and enables the investigation of local fluctuation dynamics. Our recent work using XPCS to examine ion beam nanopatterning has shown rich structure in the development of the correlation dynamics as seen in the evolving correlation time and fluctuation relaxation exponent as a function of length scale. On length scales of the ripple structure, local structure becomes ever more long-lived as coarsening progresses. In addition, the correlation peak develops a peak on length scales corresponding to the ripple wavelength, a behavior reminiscent of de Gennes narrowing. As patterning progresses, correlation times become asymmetric between the positive and negative directions, suggesting the possibility of different dynamics on the slopes facing toward and away from the ion beam. Relaxation exponents show evolution from linear dynamics at early times to compressed exponential relaxation at low wave numbers, and stretched exponential relaxation at high wave numbers. Compressed exponential behavior is reminiscent of stress relaxation processes observed in glasses, though these general behaviors can be reproduced in simulations of a nonlinear model which does not explicitly include stress relaxation. Finally, it is shown that speckle motion during the surface evolution can be analyzed to determine spatial inhomogeneities in erosion rate and ripple velocity. This allows the direction and speed of ripple motion to be measured in a real time experiment.

This research is partly supported by NSF DMR-2117509

Myint **et al**. **Phys. Rev. Lett. 126**, 016101 (2021); **Phys. Rev. B 103,** 195423 (2021); **Phys. Rev. B 103**, 195424 (2021).

Abstract 53 MON-AR-NST-05-2 Invited Talk - Monday 2:30 PM - Arabian

Theory of Nanoscale Patterns Produced by Ion Bombardment of Solid Surfaces

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Nanoscale pattern formation on the surface of a solid that is bombarded with a broad ion beam is considered for angles of ion incidence just above the threshold angle for ripple formation (1)In the case of two diametrically opposed, obliquely-incident beams, the equation of motion close to threshold and at sufficiently long times has been rigorously shown to be a simplified version of the anisotropic Kuramoto-Sivashinsky equation (1)When the surface is bombarded with a single obliquely incident beam, linear dispersion plays a crucial role close to threshold and dramatically alters the behavior: highly ordered ripples can emerge at sufficiently long times, a finding that may prove to be very useful in applications. A generalized crater function formalism that rests on a firm mathematical footing was developed and used in deriving the equations of motion for the single and dual beam cases.

Farther above threshold, a cubic nonlinearity that results from an improved approximation to the sputter yield can become important. This term can lead to the formation of a terraced topography that coarsens in time [3,4], in accord with experimental observations. For different ranges of the parameters, the theory predicts the formation of unterraced topographies that are remarkably similar to those seen in various experiments, including elongated pyramids and isolated lens-shaped depressions.

Bombardment of a solid with ions that have an energy below the sputtering threshold also produces nanoscale patterns. If the solid is bombarded with diametrically opposed, obliquely-incident beams, highly ordered, faceted ripples can emerge for angles of incidence just above threshold [5].

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Abstract 191 MON-AR-NST-05-3 Invited Talk - Monday 2:30 PM - Arabian

Compositional Changes Under Low-Energy Ion Beam Irradiation of Disordered Alloys

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Bulk metallic glasses (BMGs) and high entropy alloys (HEAs) are two unique classes of emergent alloys with unique material properties (1)For example, BMGs exhibit excellent corrosion resistance, enhanced mechanical properties and irradiation resistance. The use of low-energy ion beams between 0.1-1.0 keV at various fluences between 10^15-10^19 cm^-2 and at room temperature have led to self-organized surface nano patterning in compound semiconductors (2)In this work we examine unique response of BMG and HEAs to irradiation to low-energy ion beams utilizing in-situ surface characterization. In particular, we study properties that have implications with unique surface-relevant properties in plasma-material interaction applications for nuclear fusion devices, bioactive response and enhanced optical properties.

In-situ X-ray photoelectron and low-energy ion scattering spectroscopies (XPS, LEISS) are used to characterize the compositional changes during ion-beam irradiation of two types of BMGs: Zr52.5Cu17.9Ni14.5Al10.0Ti5.0 (Vit 105) and Zr50Cu40Al10, and correlated to nano patterning and surface mechanical property variation under irradiation. Irradiation by Ar and Kr singly-charged ions at various fluence and incident angle conditions is used. Results indicate that highly-ordered patterns can be induced only if a controlled amount of additive metallic impurities exceeded a certain threshold. Patterning is associated with a number of stages: emergence of initial random dots, subsequent transition to ripples, and

ordering of the ripple pattern through annihilation reactions of mobile defects, while the wavelength and amplitude remain invariant throughout the patterning.

Abstract 85 MON-AR-RE-01-1 Invited Talk - Monday 2:30 PM - Pioneer IV

Experiment with simulation studies of heavy ion radiolysis of aqueous systems

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Understanding the production of radical and molecular species in the radiolysis of aqueous systems is centrally important to elucidating and predicting the corrosion of nuclear plant and the degradation of used nuclear fuel disposal packages. Scavenging experiments coupled with stochastic track structure and kinetics simulations have been developed and used to determining and understand the yields and time dependence of radical species produced in the radiolysis of aqueous systems with protons, helium ions and carbon ions. Numerical extrapolation of the experimental results at slightly different ion energies in combination with data from gamma radiolysis experiments allows a systematic analysis of both track average and track segment yields with considerable track chemistry found to occur on the nanosecond to microsecond time scale. Track chemistry calculations utilizing Monte Carlo track structure simulations and nonhomogeneous independent reaction times diffusion-reaction modeling of radical and product yields reproduce experimental observations. Subsequently, the track simulation methods were used to predict radiation chemical kinetics under a variety of technologically and medically significant conditions. The results offer insight into the potential for indirect radiation induced damage to technologically and biological systems exposed to ions with very different track structures.

Abstract 230 MON-AR-RE-01-2 Contributed Talk - Monday 2:30 PM - Pioneer IV

In situ monitoring of heavy liquid metal and molten salt corrosion under simultaneous irradiation with particle-induced x-ray emission (PIXE) spectroscopy

Franziska Schmidt[1,2], Matthew Chancey[1], Hyosim Kim[1], Scott Parker[1], Peter Hosemann[2], Yongqiang Wang[1]

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[(2)]UC Berkeley, Berkeley CA, United States

Heavy liquid metals (HLM) and molten salts (MS) are important candidates for the next generation of nuclear reactor coolants. Understanding irradiation-corrosion effects in materials exposed to these coolants typically requires extensive post-experiment analysis, which only provides snapshots of the process. In this talk, we will present an overview of in situ thickness measurements of model materials under HLM and MS corrosion and simultaneous proton irradiation in the irradiation-corrosion experiment (ICE). Results are obtained using partice-induced x-ray emission (PIXE) spectroscopy, which continuously measures x-ray emissions from the beam spot and yields in situ observations of bulk changes in the irradiated region over time. The in-situ PIXE estimates of the sample thickness in the irradiation-corrosion region will be compared with ex-situ measurements of the cross section via microscopy.

Abstract 75 MON-AR-RE-01-3 Invited Talk - Monday 2:30 PM - Pioneer IV

High Throughput Study of Hardening, Void Swelling and Corrosion in Ion Irradiated High Entropy Alloys

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Engineering Physics, University of Wisconsin-Madison, Madison WI, United States

The development of next-generation nuclear reactors, operating at higher temperatures and under extreme environments, requires the generation of new alloys for claddings, internals, and structural materials. These materials are required to have excellent mechanical properties and corrosion resistance even after being neutron-damaged at high temperatures for a long time. High Entropy Alloys (HEAs) are a new class of alloys and can be described as alloys with several principal elements and no elements > 35 at%. HEAs have some promising properties for nuclear applications, such as high-temperature strength, high specific strength, and enhanced radiation tolerance. However, investigating the mechanical behavior of this new family of alloys under irradiation presents some challenges: 1. Metallurgic study of a large number of alloys is both expensive and time-consuming. As there are more than 4 elements in HEAs, the study time linearly increases with the number of alloys. In this work, our goal was to find ways to study a large number of alloys in a reasonable period of time. To achieve this goal, we developed high throughput capabilities: 1. We first used CalPhad simulation to predict the phase composition of 100 alloys of the CrFeMnNi system. 2. Direct energy deposition additive manufacturing was used to print 100 unique alloys in about 20 hours. 3. Samples have then been irradiated at UW-Madison Ion Beam Laboratory using the high throughput and high-temperature irradiation ion beam line. 4. Void swelling and irradiation-induced hardening has been measured using high throughput techniques (profilometry and nano-indentation, respectively). 5.Data have been analyzed using Machine learning to get a model able to predict radiation tolerance of the CrFeMnNi system. Moreover, post-radiation corrosion test, including water corrosion and molten salt corrosion, were performed on the HEAs and combined with the high throughput methods.

Abstract 219 MON-AR-RE-01-4 Contributed Talk - Monday 2:30 PM - Pioneer IV

Using a Small Pelletron to Simulate Space Radiation for CAPE

John Miller, William A Hollerman, Noah P Bergeron

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Recently, luminescent materials have been proposed for use to measure incident radiation fluence. Research has shown that proton bombardment in the keV to MeV range, like that occurring in space, reduces the intensity of fluorescence. Beams from small accelerators, such as the model 5SDH-2 tandem Pelletron at the Louisiana Accelerator Center (LAC), can easily be used to simulate proton exposure in space. The half brightness fluence ($\mathbf{N_{1/2}}$) is a useful figure of merit to evaluate the degradation of luminescence and is defined as the amount needed to reduce the luminescent intensity to half of its original value.

Europium tetrakis (EuD_4TEA) was exposed to 3 MeV protons using the LAC Pelletron. It was mounted to an electrically isolated translational holder with a cylindrical Faraday cup. The beam current was kept small to minimize sample charging and heating. The average 3 MeV proton $\mathbf{N_{1/2}}$ for the EuD_4TEA and PPMS paint sample was measured to be 2.83×10^{10} mm^{-2}. This measured $\mathbf{N_{1/2}}$ is almost a thousand times smaller than was found for other measured materials, which is reasonable since EuD_4TEA is an organic compound. Organics are often fragile and thus more susceptible to radiation damage. According to Tribble, a spacecraft at 1 AU from the sun will receive a 1 MeV proton fluence of less than about 10^{11} mm^{-2} from a large solar event. Likewise, 1 MeV proton fluences in the Earth's radiation belts and the Earth-Moon-Sun Lagrange points will be even less than the 10^{11} mm^{-2} value from large solar events. For that reason, EuD_4TEA should be a good candidate for use as a proton fluence sensor for spacecraft.

Some time ago, the Cajun Advanced Picosatellite Experiment (CAPE) program at the University of Louisiana at Lafayette began developing student-built satellite projects for launch into space. The first CAPE-1 1U CubeSat was launched in April 2007 from the Baikonur Cosmodrome in Kazakhstan. The second CAPE-2 1U CubeSat was launched in November 2013 from the NASA Wallops Island Flight Facility in Virginia. These missions were designed to develop the skills and techniques needed for controllers to communicate with a satellite in space.

About six years ago, work was started to measure proton fluence in space using EuD_4TEA. The Astronaut-Wearable Radiation Meter for Operation in Potential Radiation Environments (ARMOR) payload was an integral part of the 1U CAPE-3 CubeSat that was sent aloft by Virgin Orbit in January 2021. A small PMMA and EuD_4TEA sample had direct exposure to space. At desired times, a diode illuminated the EuD_4TEA sample causing it to emit its characteristic 611 nm luminescence, which was detected in a silicon photodiode. A notch optical filter was placed on top of the photodiode so

only light with wavelengths near 611 nm is detected and recorded. Blocker plates/baffles were used to minimize stray light hitting the photodetector. During operation, the ARMOR payload recorded luminescence collected by the photodiode from the sample as a function of time. The proton fluence in space can be estimated by knowing the orbital trajectory of the satellite, the degradation of luminescence from the sample, and the measured count rate from a co-located student-built Geiger counter/monitor.

However, for a variety of reasons, no radiation exposure data was returned to Earth from CAPE-3. It was decided to design and build an improved ARMOR payload to fly on the upcoming CAPE-4 CubeSat, which should be launched in a few years. The larger 3U CAPE-4 satellite will use multiple samples positioned in different spatial orientations and with varying amounts of absorber materials. A normal proton detector will also be flown to provide a direct comparison with the luminescence results. In place of a Geiger counter, one or more modified cell phone cameras will be used to measure gamma-ray fluence. CMOS image sensors on common cell phones are known for their sensitivity to gamma-rays. Interaction of gamma-rays with the CMOS will appear as flashing bright spots on the image. This presentation will discuss results from the recently completed CAPE-3 mission. It will also give insights into the improved ARMOR payload that is scheduled to fly on CAPE-4. Emphasis will be placed on the testing and materials analysis of payload components using the LAC Pelletron accelerator.

Abstract 16 MON-PR-SP-02-1 Invited Talk - Monday 2:30 PM - Palomino

β-Oslo measurements for the r-process with next generation accelerator facilities

Erin C Good

Facility for Rare Isotope Beams (FRIB), East Lansing Michigan, United States

The astrophysical rapid neutron capture process, or r-process, is responsible for the production of over half the elements heavier than iron. With the advent of facilities that can finally produce some of these isotopes, like the Facility for Rare Isotope Beams (FRIB) at Michigan State University or the N=126 Factory at Argonne National Lab (ANL), we have the first opportunities to make experimental measurements of some of the quantities important in modeling the r-process. As the most exotic nuclei will be produced at very low rates, direct measurements of neutron capture reactions will remain unfeasible. Therefore, experimental techniques that still allow us to utilize the low production of these beams are essential. One such technique, the β-Oslo method, allows us to experimentally determine nuclear properties and use them to constrain theoretical calculations of neutron capture cross sections while requiring only hundreds of particles per second. Here I will discuss how the β-Oslo method works by showing previous results from the National Superconducting Cyclotron Laboratory (NSCL) and the Californium Rare Isotope Breeder Upgrade (CARIBU) facility at ANL, as some proposed and possible candidates for measurements relevant to the r-process with this technique.

Abstract 65 MON-PR-SP-02-2 Invited Talk - Monday 2:30 PM - Palomino

Mass measurements for the r-process using Canadian Penning Trap

Biying Liu[1,2], Maxime Brodeur[1], Daniel Burdette[2], Jason Clark[2], Graeme Morgan[2,6], Rodney Orford[5], William Sam Porter[1], Dwaipayan Ray[2,3], Fabio Rivero[1], Guy Savard[2,4], Kumar Sharma[3], Adrian Valverde[2,3], Louis Varriano[2,4]

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The rapid neutron capture process (r-process) is responsible for the production of almost half of the natural elements heavier than iron. Precise and accurate masses of neutron-rich isotopes are needed for reliable r-process abundance calculations for the models of neutron star merger and other potential astrophysical sites. The Canadian Penning Trap

(CPT) has been at the Argonne National Laboratory's CARIBU facility for over a decade, where it measured the masses of over 300 nuclei produced from the spontaneous fission of CARIBU's 252Cf source with a typical precision of around 10 keV. In the past few years, masses of interest to the formation of the rare-earth peak in the r-process abundance pattern were measured using the CPT. This fall, the CPT will be relocated at the future N=126 Factory to probe the masses around the $N=126$ shell closure while also reaching further away from stability in the rare-earth region.

Abstract 143 MON-PR-SP-02-3 Invited Talk - Monday 2:30 PM - Palomino

Study of ^{86}Kr(α, n) in inverse kinematics using SECAR

Caleb Marshall

The Institute of Nuclear and Particle Physics, Ohio University, Athens Ohio, United States

Stars in the galactic halo show near identical abundance patterns for most r-process nuclei, indicated a universality to the primary site of the r-process. However, for abundances from Strontium to Silver, these very same stars show a significant scatter hinting at a different astrophysical origin. The neutrino driven winds of core collapse supernovae provide a possible explanation for these observations. In these explosive environments (α, n) reactions close to stability drive heavy element enrichment. (α, n) cross sections on these nuclei are derived from theory, which is in turn sensitive to nuclear input that is lacking in this region of importance. Direct measurements of these (α, n) cross sections at astrophysical energies are therefore essential ingredients for our nuclear and stellar models. In this talk I will discuss a novel technique for measuring these reactions in inverse kinematics using a recoil separator to detect the heavy reaction products in coincidence with neutrons. The first measurements of this type have been carried out using The Separator for Capture Reactions (SECAR) located within ReA3 at FRIB. Principles of the experimental technique will be described along with a discussion of the technical challenges of using SECAR for this specific purpose.

Abstract 92 MON-PR-SP-02-4 Contributed Talk - Monday 2:30 PM - Palomino

High power DC and nanosecond pulsed 2 MV accelerator for light ions

Andrey Shornikov[1], Arthur Champagne[2], Dirk Mous[1], Rob Walet[1]

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[(2)]Physics, The University of North Carolina at Chapel Hill, Chapel Hill North Carolina, United States

High Voltage Engineering developed, built and tested a unique 2 MV single-ended accelerator (Singletron™) for light ions that combines up to 2mA beam current for H and He in direct-current mode with nanosecond-pulsing capability. The all solid-state Singletron 2 MV power supply™ supports high-current operation and features a large dynamic range of the terminal voltage as well as good transient performance to support the high-current operation. The terminal accommodates an in-house developed 2.45 GHz ECR ion source and a chopping-bunching system that features phase-locked loop stabilization and temperature compensation of the excitation voltage and its phase. The chopping bunching system further features selection of H, D and He as well as pulse repetition rate, ranging from 125 kHz to 4 MHz, that are fully computer controlled.

In the testing phase the system demonstrated smooth operation for 2 mA H and He beams at a terminal voltage of 0.5 - 2.0 MV, and somewhat reduced current at a voltage down to 250 kV. In pulsing mode, pulses with 2.0 ns FWHM reached a peak current of ~10 mA and ~5.0 mA for Helium and protons, respectively, equivalent to a charge of ~20 and ~10 pC in the pulse. Applications range from various fields requiring direct current multi-mA level, MeV light ions, including nuclear astrophysics research.

Abstract 55 MON-PR-SP-02-5 Contributed Talk - Monday 2:30 PM - Palomino

New Tools for Explosive Nucleosynthesis Studies at the Notre Dame Nuclear Science Lab (NSL)

D. W. Bardayan, S. Carmichael, P. D. O'Malley, T. Ahn, C. Boomershine, S. Coil, M. Couder, D. Robertson, A. Simon, E. Stech, S. Thomas, W. von Seeger

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Explosive nucleosynthesis occurs in a number of astrophysical environments including novae, supernovae, and X-ray bursts. Reactions on unstable nuclei critically determine the properties of these astrophysical explosions but are difficult to measure directly owing to the relatively low intensities of these at current-generation radioactive beam facilities. At the NSL, new equipment is being developed and installed in order to indirectly determine these astrophysical reaction rates on unstable nuclei. The Solenoid Spectrometer for Nuclear Astrophysics and Decays (SSNAPD) will utilize the first solenoid of TriSol to measure decay branching ratios as low as 10^{-5} originating from exotic nuclei. Second, an Enge Split-Pole Spectrometer has been transferred from Oak Ridge and is being installed at the NSL. These projects, their status, and plans will be discussed.

Research sponsored by the National Science Foundation and the University of Notre Dame.

Abstract 190 TUE-PS-AC-01-1 Plenary Talk - Tuesday 8:45 AM - Kincaid

Spallation Neutrons and Applications

Kenneth Herwig

Second Target Station Project, Oak Ridge National Laboratory, Oak Ridge TN, United States

The Spallation Neutron Source (SNS) at Oak Ridge National Laboratory is the world's most powerful pulsed neutron source. The SNS accelerator currently provides 1.4 MW of proton beam power in short, less than a microsecond, pulses incident onto a liquid mercury target at 60 Hz. The spallation neutrons produced are reduced in energy in one of the hydrogen-rich moderators located close to the target. Neutrons exiting the moderators enter beamlines which guide the neutrons to end stations where they are incident on samples. Neutrons scattered from the samples are measured in detectors arranged around the sample. The time between proton pulses is used to stretch out the arrival of different energy neutrons at the sample, enabling time-of-flight method determination of neutron velocity. The short-pulse nature of the proton pulse enables high-resolution neutron wavelength measurements of the structure and internal motions of materials at the atomic to the nanoscale. The original SNS project completed construction in 2006 with provision in its design to increase accelerator power and add a future target station. The Proton Power Upgrade Project will double the capability of the SNS accelerator to 2.8 MW while the Second Target Station Project will add a new set of neutron scattering capabilities. This talk will review production and operation of the neutron source, discuss the two ongoing major upgrade projects, and illustrate the types of materials science currently done at the SNS with a few examples.

Abstract 261 TUE-AP-IA-02-1 Invited Talk - Tuesday 10:00 AM - Quarter

Reducing the Radiological Risk by Encouraging Electron Beam and X-Ray Adoption

Jennifer Elster[1], Suresh Pillai[2], Oscar Acuna[2]

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The use of ionizing energy is widely used in agriculture, industrial, and medical applications. The legacy use of irradiation practices using high activity Cobalt 60/Cesium-137 facilities for these applications has recently been challenged from a security and sustainability perspective. The Cobalt-60 shortages and the risk driven switch to alternative has generated numerous questions from researchers on the feasibility of switching from gamma to X-ray or eBeam for these activities.

While this presentation will review advantages of eBeam in current and emerging markets, also addressed are key projects/collaborations underway at PNNL to eliminate barriers to transitioning from Cobalt-60 to these alternatives. Applications such as polymer modification, environmental and wastewater remediation, crop mutation, sterile insect techniques (SIT), and medical device/donor tissue sterilization are included in the numerous projects that will address the information barrier for users considering the switch from Gamma to X-ray or eBeam. In addition to these studies, PNNL is collaborating with Texas A&M on direct partner feasibility studies for eBeam transition. These engagements aim to provide a roadmap for sites considering the transition and include details on reliable product irradiation, requirements for eBeam selection/bidding, location/supply chain considerations, electrical infrastructure, and estimated costs. This work is funded by DOE/NNSA Office of Radiological Security (ORS), with the goal of permanent security risk reduction and eliminating the possibility of adversaries acquiring radiological materials for an radiological dispersal device/"dirty bomb".

Abstract 279 TUE-AP-IA-02-2 Invited Talk - Tuesday 10:00 AM - Quarter

The use of Electronic Cold-Pasteurization (ECP) as a means of reducing movement and development of plant pests and pathogens

Chip Starns

Reveam, Inc., Norcross GA, United States

Reveam is a pioneering food safety technology company that revolutionizes the way the world's fresh food supply comes to market by eliminating pests and pathogens and extending the useful shelf-life of fruits and vegetables without impacting taste or appearance. Using our advanced electron accelerator (E-beam) technology, known as Electronic Cold-Pasteurization™ (ECP™), we are uniquely positioned to enhance quality, radically reduce food waste and food cost, and improve safety of fresh produce while advancing efforts to feed a growing world population. Recently showcased in front of 500 policymakers at the world's first International Plant Health Conference (IPHC) in London, ECP™ is recognized by leading global authorities as a truly effective and environmentally safe food treatment method available today. United around a singular focus of using science and technology to make the world's food supply safer, fresher and healthier - Reveam mends highly technical capabilities with practical commercial application to help solve the most critical issues facing the food sector today.

Abstract 218 TUE-AP-IA-02-3 Invited Talk - Tuesday 10:00 AM - Quarter

Comparison and Selection of Irradiation Sources for Medical Device Sterilization and Environmental Applications

David Staack

Mechanical Engineering, Texas A&M University, College Station TX, United States

Factors which influence selection of an accelerator for a industrial process include both accelerator parameters and end use process design variables. This work will summarize lessons learned from recent experimental campaigns on irradiation source comparison for two industries 1) polymer properties and functionality of medical devices during sterilization and 2) emerging applications for energy and the environment. Source considerations include: primary particle (electron, x-ray, gamma), source efficiency, power, dose rate, energy, penetration depth, availability, and safety requirements. Application considerations include: value added by process, acceptable dose uniformity, divisibility, minimum viable scale, and relative cost of irradiation processing. Experiments from five different irradiation sources are compared and discuss in context of five medical devices of various geometry and efficacy of environmental application in water remediation, soil remediation, energy from waste, and fuel upgrading. In general many various configuration are successful modalities but the definition of a single 'best' is elusive.

Abstract 108 TUE-AP-SD-02-1 Invited Talk - Tuesday 10:00 AM - Pioneer III

Neutrons for Border Security: A Customer's Viewpoint

Philip N Martin

Atomic Weapons Establishment, Reading Berkshire, United Kingdom

The Nuclear Threat Reduction Programme at the Atomic Weapons Establishment has comprised an element of border security since 2001 and active detection since 2007. Over the past 15 years, active detection at AWE has encompassed numerous experimental and computational modelling campaigns. These campaigns have used Neutrons, photons or both as the active source of radiation input, coupled with output neutrons and photons resulting in varying degrees of success. This diverse workstream involves close collaborative work with multiple customers, primarily the UK Home Office but also US DHS CWMD, multiple vendors, national laboratories and institutions. The role of AWE, in this medley of cutting-edge industrial research, is not that of a vendor but of Technical Authority for RN security (including active interrogation/detection) for the UK Home Office. Positioned between vendors and customers, we present our unique take on neutron generators for security and defence. Where we need to be, based on where we are and where we have come from.

Abstract 160 TUE-AP-SD-02-2 Invited Talk - Tuesday 10:00 AM - Pioneer III

Cargo Inspection Using Neutron Generators

Martin B. Smith[1], Vernon T. Koslowsky[1], Tobias Achtzehn[1], H. Robert Andrews[1], Michael Gale[1], Harry Ing[1], Martin R. Koslowsky[1], Scott J. MacEwan[1], Michael McDonald[1], Rhiannon J. Monckton[1], Eduardo Nebot del Busto[1], Douglas M. Wright[2]

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Neutron sources have been used in a wide range of inspection applications for many years. Recently, some of the methods developed, including neutron transmission imaging, die-away analysis, and gamma ray spectroscopy following neutron interrogation, have been utilized for screening of cargo in security applications. This presentation will review the status of cargo inspection using neutron generators, then discuss two systems currently under development, which aim to augment existing X-ray inspection systems in searching for explosives, narcotics, and special nuclear material.

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The remainder of the work has been jointly funded by the Department of Homeland Security Science and Technology (S&T) Directorate and Transport Canada.

Abstract 80 TUE-AP-SD-02-3 Invited Talk - Tuesday 10:00 AM - Pioneer III

Vehicle-based and Robotic Active Neutron Interrogation Systems for Threat Detection

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Rapiscan Laboratories has developed a neutron-based single-sided active interrogation threat detection system for vehicle and robotic platforms. The systems are designed to detect various threats including special nuclear material, narcotics and explosives hidden within cargo. For nuclear material detection, the system relies on detecting directly fast fission neutrons from thermal-neutron-induced fission events. For narcotic and explosive threats, the system detects both neutron-induced

inelastic and capture gamma rays. Both platforms are based on portable electronic neutron generators designed and manufactured by Starfire Industries. The vehicle-based system relies on a pulsed deuterium-tritium 14.1 MeV neutron generator, whereas the robotic system utilizes a deuterium-deuterium 2.5 MeV neutron generator. The larger vehicle-based system contains an array of large-volume NaI detectors for narcotics and explosives detection and an array of liquid scintillators for nuclear material detection. The robotic system contains Ce2Br3 detectors and liquid scintillators. We will describe the fully operational robotic and vehicle system and show signals and backgrounds from various cargoes.

Acknowledgement of Sponsorship: This work is supported under the U.S. Department of Homeland Security, Countering Weapons of Mass Destruction Office, competitively awarded contract 70RDND18C00000007. This support does not constitute an express or implied endorsement on the part of the Government.

Abstract 94 TUE-AP-SD-02-4 Contributed Talk - Tuesday 10:00 AM - Pioneer III

DT Neutron Generators for Security and Defense Applications

Jay Theodore (Ted) Cremer, Craig Brown, David L Williams, Charles K Gary

Adelphi Technology, Inc., Redwood City CA, United States

Various measurements have been made using Adelphi's neutron generators, to indicate their suitability for including:

- Pulsing

- Radiography (including fast, 14.1 MeV, neutron radiography)

- Prompt gamma-ray spectroscopy

- Associated Particle measurements (for a line of Associated Particle Imaging neutron generators)

Adelphi manufactures a range of neutron generators that produce either 14.1 MeV neutrons (originating from the reaction of deuterium and tritium, D-T), 2.45 MeV neutrons (originating from the reaction of deuterium with deuterium, D-D) and 0.025 eV/Thermal neutron generators (which are D-D generators with integrated moderators to thermalize the neutrons).

D-T neutron generators are particularly suitable for security and defense applications because of the penetrating nature of 14.1 MeV neutrons. Adelphi's DT generator has a yield of 1.2x10^10 n/s (measured using a Bonner ball).

The D-T fusion cross section is significantly higher than the D-D fusion cross section, so much less power is required to achieve a given neutron yield. D-T neutron generator technology is consequently well-suited to applications requiring portability.

One such application we have considered is the mounting of neutron generators on aerial drones for potential landmine and improvised explosive device (IED) detection. Such applications require extremely compact neutron generators that are light weight and low power.

D-T generators that we presently have in development are spec'd to be <20 lbs and consume 50 Watts of power operating at 10^9 n/s, scaling to 150 Watts for 10^10 n/s, which could make such approaches feasible.

Other applications for security include Fast Neutron Radiography (FNR). Intense D-T neutron sources are much more compact than their D-D counterparts which brings the possibility of taking the radiography system to the object, rather than bringing the object to the neutron source, thus enabling field applications.

The radiographic contrasts obtained by 14.1 MeV FNR are similar to those obtained with high-energy X-ray and gamma-ray radiography and in general are finer than those achieved with thermal neutron radiography.

However, unlike with X-ray and gamma-ray radiography, the broader contrast latitude allows low-atomic-number materials to simultaneously be observed with heavier metals. Imaging performance has been measured using phantoms consisting of a USAF-1951 resolution target and by evaluating the modulation transfer function (MTF) by analyzing the edges of object images.

Neutron pulsing, radiography, prompt gamma-ray spectroscopy and Associated Particle Imaging have applications to security and defense and Adelphi is active in developing these technologies to address these applications.

Abstract 30 TUE-AR-NST-06-1 Invited Talk - Tuesday 10:00 AM - Arabian

The multiple impactful applications of ion beam bombardment

Carmen S. Menoni

Electrical and Computer Engineering & Chemistry, COLORADO STATE UNIVERSITY, Fort Collins CO, United States

The use of keV ion beams in combination with sputtering has enabled: broad area patterning of sub-micron structures, the modification of stress in ion beam sputtered (IBS) oxide thin films and the removal of nodule-like defects in optical multilayer dielectric coatings. The use of Xe+ ions to bombard a prepatterned periodic pattern at oblique incidence enables formation of an ordered terraced structure which is maintained after the subsequent deposition of Si/SiO2 bilayers [1]. This type of structure is found in diffraction gratings ubiquitous in optical systems. The use of keV O2+ ions during the deposition of amorphous oxide thin films alters the morphology of the growing film resulting in the reduction of the residual stress in IBS coatings, with important consequences in the engineering of multilayer dielectric coatings for high energy near infrared lasers [2]. In a similar fashion, bombarding Ar+ ions during the deposition of SiO2 in a multilayer structure can reduce nodule-like defects which affect the response of the coatings to intense laser beams [3]. These three applications are examples of the impactful technological impact of broad area ion beam bombardment.

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[3] C. Stolz, J. Wolfe, J. Adams, M. Menor, N. Teslich, P. Mirkarimi, J. Folta, R. Soufli, C. S. Menoni, and D. Patel, "High laser-resistant multilayer mirrors by nodular defect planarization," Applied Optics, vol. 53, A291-A296 (2014).

Abstract 179 TUE-AR-NST-06-2 Invited Talk - Tuesday 10:00 AM - Arabian

Defect engineering in Ga_2O_3 by ion beam irradiation and band gap tunning

Farida A. Selim[1], Minhaz Islam[1], Armando Hernandez[1], Noalick Abo[1], Yongqiang Wang[2]

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Ga_2O_3 is emerging as an exceptional potential semiconductor for high power transistors and radiation detection because of its the ultra-wide band gap and radiation hardness. Defects engineering and modulating localized states in the band gap provide interesting ways to manipulate the properties of wide band gap materials. In this talk I will show how ion beam irradiation and beam tunning are used to engineer point defects and modulate their positions in the band gap, which can lead to remarkable changes in the electronic, optical, and transport properties of Ga2O3.

This work was supported by the Center for Integrated Nanotechnologies, an Office of Science User Facility operated by the U.S. Department of Energy (DOE) Office of Science.

Abstract 156 TUE-AR-NST-06-3 Contributed Talk - Tuesday 10:00 AM - Arabian

Isotropic swelling as a mechanism for nanopattern suppression

Jennifer Swenson, Tyler Evans, Scott A Norris

Mathematics, Southern Methodist University, Dallas TX, United States

It has long been observed experimentally that energetic ion-beam irradiation of semiconductor surfaces may lead to spontaneous nanopattern formation. For most ion/target/energy combinations, the patterns appear when the angle of incidence exceeds a critical angle, and the models commonly employed to understand this phenomenon exhibit the same behavioral transition. However, under certain conditions, patterns do not appear for any angle of incidence, suggesting an important mismatch between experiment and theory.

Recent work by our group [Swenson and Norris, **J. Phys.: Condens. Matter 30** (2018) 304003; Evans and Norris, **J. Phys.: Condens. Matter 34** (2022) 325302] proposed including the mechanism of radiation-induced swelling as a means of addressing this mismatch. These works used a combination of analytical and numerical approaches to show that such swelling is indeed stabilizing at all angles of incidence, and may therefore explain the observed suppression of ripples. Our findings strongly support the inclusion of a swelling mechanism in models of pattern formation under ion beam irradiation, and highlight the need for more - and more detailed - experimental measurements of material stresses during pattern formation.

Abstract 161 TUE-AR-NST-06-4 Contributed Talk - Tuesday 10:00 AM - Arabian

Physical mechanisms affecting critical angle for nanopatterning in irradiated semiconductors

Tyler Evans, Scott A Norris

Mathematics, Southern Methodist University, Dallas TX, United States

Ion-beam irradiation of an amorphizable semiconductor such as Si or Ge may lead to spontaneous pattern formation beyond some critical angle of the beam relative to the surface normal. Although the most well-studied system (Ar->Si) exhibits a transitional angle consistent with the simplest theoretical treatments, it has been shown that this critical angle varies considerably according to beam energy, ion species and target material, and attempts to theoretically explain these variations has remained a challenge.

In this talk, we present and analyze a composite model with a number of novel features

(a) combined treatment of stress with both (anisotropic) plastic flow and (isotropic) swelling

(b) an arbitrary depth dependence profile for the strength of each of these two effects.

(c) a novel configuration for the lower interface condition based on the Sigmund Ellipses.

We show how the various parameters in the model (relative strength of swelling vs. plastic flow, degree of depth dependence in the mechanisms, and precise location of the lower interface) affect the stability of the system and hence the critical angle. In the process, we rule out some existing hypotheses, and present new open questions.

Abstract 201 TUE-AR-RE-06-1 Invited Talk - Tuesday 10:00 AM - Kincaid (Hybrid)

Radiation effects in MAX phases

Chenxu Wang

School of Physics, Peking University, Beijing, China

Atomic disordering in materials alters their physical and chemical properties and can subsequently affect their performance in advanced nuclear systems. In complex ceramic materials, it is a challenge to understand the nature of structural disordering, due to the difficulty of direct, atomic-scale experimental observations. $M_{n+1}AX_n$ phases, where M represents an early transition metal, A represents an A-group element, X represents carbon or nitrogen, and n = 1, 2, or 3, exhibit highly ordered hexagonal nano-layered structures (P63/mmc) consisting of n layers of edge-sharing M6X octahedra interleaved by close-packed A layers. Owing to this complex characteristic structure, this class of compounds exhibits unique combinations of properties typical of both metals and ceramics, such as easy machinability, high-temperature strength, high electrical and thermal conductivities, and excellent oxidation and corrosion resistance. In this talk, I will show the direct observation of irradiation-induced antisite defects in $M_{n+1}AX_n$ phases and chemical disordering using high-resolution aberration-corrected STEM HAADF and ABF imaging and provide compelling evidence of order-to-disorder phase transformations. This result overturns the conventional view that irradiation causes phase decomposition to binary fcc-structured $M_{n+1}X_n$. With the formation of uniformly distributed cation antisite defects and the rearrangement of X anions, an order-to-disorder, hex-to-γ-to-fcc phase transformation leads to the formation of metastable solid solution phases, wherein the M and A atoms occupy a single cation site with the ratio of n+1:1 and the X atoms are located at the anion sites with the occupancy of n/(n+2). Subsequent characterization by atom probe tomography (APT) shows that the A atoms were randomly distributed in the structure of the solid solution phases. Grazing incidence X-ray diffraction (GIXRD) and first-principle calculations elucidate the precise structural parameters of these disordered phases, and further suggest that this unique disordering process yields desirable changes to the properties of the materials. This study provides a comprehensive understanding of the order-to-disorder transformations in $M_{n+1}AX_n$ phases and proposes a method for the synthesis of new solid solution $(M_{n+1}A)X_n$ phases by tailoring the disorder.

Abstract 208 TUE-AR-RE-06-2 Contributed Talk - Tuesday 10:00 AM - Kincaid (Hybrid)

The contribution of irradiation effect in ferromagnetic semiconductors

Ye Yuan[1], Shengqiang Zhou[2]

[(1)]*Songshan Lake Materials Laboratory , Dongguan Guangdong , China*
[(2)]*Institute of Ion Beam Physics and Materials Research, Helmhotz-Zentrum Dresden-Rossendorf, Dresden, Germany*

In the present work, the uniaxial magnetic anisotropy of GaMnAsP is modified by helium ion irradiation. According to the micro-magnetic parameters, e.g. resonance fields and anisotropy constants deduced from ferromagnetic resonance measurements, a rotation of the magnetic easy axis from out-of-plane [001] to in-plane [100] direction is achieved. From the application point of view, our work presents a novel avenue in modifying the uniaxial magnetic anisotropy in GaMnAsP with the possibility of lateral patterning by using lithography or focused ion beam.

Abstract 206 TUE-AR-RE-06-3 Invited Talk - Tuesday 10:00 AM - Kincaid (Hybrid)

Self-powered and flexible gas sensor using defect-engineered 2D heterostructure

Xiaofei Ma, Xiaofan Cai, Yang Tan

School of Physics, Shandong University, Jinan, China

Two-dimensional (2D) Transition Metal Dichalcogenides (TMDCs) are considered leading candidates for ultrathin and wearable gas sensors, owing to their unique properties, including high sensitivity to gas adsorption and flexibility. However, the ongoing Internet of Things (IoT) revolution further puts forward requirements of self-contained power for future gas sensors, and the study of the self-power performance of 2D TMDCs gas sensors to date has lagged behind other characteristics. Here, we demonstrate a photovoltaic self-powered gas sensor based on the defect-engineered WS_2/G heterostructure, exhibiting excellent sensing performances, including ultra-sensitivity, and fast response. Defects induced by the ion irradiation engineer the homogeneous WS_2/G into a heterogeneous $WS_{2-0.2}$/G-WS_2/G forming a Schottky diode with photovoltaic functions. Driven by the indoor light (500 Lx, 0.9 mW/cm^2), this $WS_{2-0.2}$/G-WS_2/G heterostructure identifies NO_2 gas by the positive change of the photocurrent and the limit of detection (LOD) toward NO_2 is 50 ppb with a response time of 110 s. The sensing performance of the defect-engineered heterostructure remains stable even after 1000 cycles of bending, confirming the application potential as a flexible device. This work presents an efficient strategy for preparing the self-powered gas sensor based on two-dimensional materials, meeting the emerging Internet of Things requirements.

Abstract 32 TUE-AR-RE-06-4 Invited Talk - Tuesday 10:00 AM - Kincaid (Hybrid)

Enhanced (Photo)electrocatalytic properties by ion beam technology

Feng Ren, Huizhou Zhong, Derun Li

School of Physics and Technology, Wuhan University, Wuhan Hubei, China

(Photo)electrochemical energy storage and conversion technology is an important part in the development of environmentally friendly, efficient and universal access renewable energy technology. Ion beam technology is a powerful and versatile physical method in modification of various catalytic materials from the surface to interface and thin film can be realized by controlling the species, energy, fluence of implanted ions. Ion beam technology has its unique advantages, including its compulsivity of element doping and its high controllability, accuracy and repeatability. This makes it possible for the ion beam technology to adapt to the modification requirements of catalytic materials to tailor the electronic structure, interface structure and morphology of the materials more finely. In this work, we simultaneously realize the two kinds of regulation in a catalyst by using unique ion irradiation technology. A nanosheet structured NiO/$NiFe_2O_4$ heterostructure with rich oxygen vacancies converted from NiFe LDH by Ar^+ ions irradiation shows significant enhancement in both OER and HER performance. Density functional theory (DFT) calculations reveal that the construction of NiO/$NiFe_2O_4$ can optimize the free energy of O^* to OOH^* process during OER reaction. The oxygen vacancy-rich NiO/$NiFe_2O_4$ nanosheets have an overpotential of 279 mV at 10 mA cm^{-2} and a low Tafel slope of 42 mV dec^{-1}. Moreover, this NiO/$NiFe_2O_4$ electrode shows an excellent long-term stability at 100 mA cm^{-2} for 450 h. The synergetic effects between NiO and $NiFe_2O_4$ make NiO/$NiFe_2O_4$ heterostructure have high conductivity and fast charge transfer, abundant active sites, and high catalytic reactivity, contributing to its excellent performance.

Abstract 45 TUE-PR-SP-03-1 Invited Talk - Tuesday 10:00 AM - Palomino

The Nuclear Pear Factory

Jaideep Taggart Singh

Facility for Rare Isotope Beams, Michigan State University, East Lansing MI, United States

We are proposing the creation of "The Nuclear Pear Factory," which will bring together a diverse international team of scientists

across disciplines towards a common goal to search for physics beyond the Standard Model of

particle physics with unprecedented sensitivity by leveraging new access to previously inacces-

sible exotic atomic nuclei. Some of these atomic nuclei have "pear-shaped" deformations which

are predicted to enhance their intrinsic sensitivity to new physics by a factor of 1,000 to 1,000,000

more than stable isotopes with nearly spherical atomic nuclei. The Facility for Rare Isotope Beams

(FRIB) at Michigan State University will produce many of these rare isotopes in abundance, some

for the first time. Precision atomic and molecular physics experiments enabled by FRIB have the

potential to make unprecedented advances in the search for new physics in the nuclear sector.

However, designing and developing these complex and innovative experiments and maxi-

mizing their scientific impact requires large-scale, long-term awards, and increased coordination

across various disciplines. Currently these efforts are either piecemeal or non-existent. The Nuclear Pear Factory will address this deficiency by addressing the following needs: (1) radiochemistry to produce the harvested isotopes in the appropriate chemical form needed for the experiments, (2) atomic, molecular, and optical physics experiments to carry out precision measurements

of the relevant observables (3) theory support in this area to quantify laser-electron and electron-

nucleus interactions as well as to develop new techniques, (4) a tightly integrated nuclear physics

theoretical and experimental effort to calibrate the sensitivity of these isotopes to new physics, (5)

Lattice Quantum Chromodynamics to translate these exotic interactions from nucleon and meson

degrees of freedom to quark and gluon degrees of freedom, and (6) particle physics theory to con-

textualize the new physics and their resulting interactions between elementary particles.

Abstract 199 TUE-PR-SP-03-2 Invited Talk - Tuesday 10:00 AM - Palomino

Infrastructure for radioactive molecule production at CERN-ISOLDE

Sebastian Rothe[1], Mia Au[1,2], Mark Bissel[1], Maximilian Schütt[1], Simon Stegemann[1], Edgar Reis[1,3]

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[(2)]Johannes Gutenberg-Universität Mainz, Mainz, Germany
[(3)]University of Duisburg-Essen, Essen, Germany

ISOLDE is CERN's radioactive ion beam factory, where rare isotopes are created through bombarding a thick target with protons at an energy of 1.4 GeV.

The radioisotopes diffuse out of the target matrix and are ionized, accelerated to 60keV, thus forming an ion beam of typically singly charged ions, which are mass-separated using dipole mass separators.

The creation of radioactive molecules has typically been rather a necessity where, especially for refractory elements, the formation of a volatile molecule is required to release the short lived isotopes from the target. In many cases, the user is unaffected from the form in which the radioisotope is delivered to their experiment.

In 2018 the CRIS experiment performed laser spectroscopy on radium fluoride (RaF) at CERN-ISOLDE. Here, the users actually wanted to study the molecule. This experiment has added another good reason to produce and develop new molecular beams at rare isotope facilities.

We will present how isotopes are produced at ISOLDE and motivate molecular ion beams. We will show existing and planned infrastructure to create and study molecules in the off-line and on-line laboratories. We will close with highlights of the most recent results and ongoing studies.

Abstract 200 TUE-PR-SP-03-3 Invited Talk - Tuesday 10:00 AM - Palomino

Developments for actinide molecular ion beams at CERN-ISOLDE

Mia Au[1,2], Michail Athanasakis-Kaklamanakis[1,3], Jochen Ballof[7], Robert Berger[4], Katerina Chrysalidis[1], Paul Fischer[9], Reinhard Heinke[1], Jake Johnson[3], Ulli Köster[5], Bruce Marsh[1], Maxime Mougeot[10], Lukas Nies[1,9], Jordan Reilly[6], Moritz Schlaich[8], Christoph Schweiger[1,10], Simon Stegemann[1], Julius Wessolek[6], Frank Wienholtz[8], Shane Wilkins[11], Wiktoria Wojtaczka[3], Christoph Düllmann[2,12,13], Sebastian Rothe[1]

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(7)FRIB, East Lansing Michigan, United States
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(11)Massachusetts Institute of Technology, Cambridge Massachusetts, United States
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The ISOLDE facility at CERN provides experiments with ion beams of isotopes across the nuclear chart produced in reactions between 1.4 GeV protons and thick targets. The development of molecular ion beams is motivated by improvements to beam extraction and purity as well as interest in studying radioactive molecules. Molecules have been studied as a method to efficiently deliver beams of release-limited elements by forming and extracting volatile molecules [1,2] of otherwise refractory species such as carbon [3], boron [4] or refractory metals (5)Molecular sideband extraction is also used as a technique to improve beam purity. Molecules additionally provide opportunities for fundamental physics at radioactive beam facilities [6,7,8].

We present first results of actinide molecular ion beam development at ISOLDE. Uranium carbide targets were used to produce molecular beams via injection of reactive tetrafluoro methane (CF_4) gas. The ion beam composition was studied using: the ISOLTRAP Multi-Reflection Time-of-Flight Mass Spectrometer (MR-ToF MS) [9] for identification by ToF mass measurements, online γ-ray spectroscopy at the ISOLDE tape station [10,11], and off-line α- and γ-ray spectrometry of ion-implanted samples. The results contribute to beam developments for actinide elements and radioactive molecule production for fundamental physics research.

This project has received funding from the European's Union Horizon 2020 Research and Innovation Programme under grant agreement number 861198 project 'LISA' (Laser Ionization and Spectroscopy of Actinides) Marie Sklodowska-Curie Innovative Training Network (ITN).

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Abstract 98 TUE-PR-SP-03-4 Contributed Talk - Tuesday 10:00 AM - Palomino

Optimized high-throughput analysis technique for a dual-axis duo-lateral position-sensitive silicon detector for excellent position and energy resolution

Andy Hannaman[1,2], Alan McIntosh[2], Kris Hagel[2], Bryan Harvey[2], Travis Hankins[1,2], Austin Abbott[1,2], Jerome Gauthier[2], Yiuwing Lui[2], Laura McCann[1,2], Lauren McIntosh[2], Steven Schultz[1,2], Maxwell Sorensen[1,2], Zach Tobin[1,2], Roy Wada[2], Sherry Yennello[1,2]

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[(2)]Texas A&M University Cyclotron Institute, College Station Texas, United States

The dual-axis duo-lateral (DADL) position-sensitive silicon detector was developed to obtain precise position and energy information for detected charged particles. The Forward Array Using Silicon Technology (FAUST) is currently equipped with 68 DADL detectors backed by CsI(Tl) scintillators for the study of charged particle correlations in heavy-ion collisions where precise position and energy information is essential. When conventional signal processing electronics were used for the DADL detectors, a position dependence of the measured energy and distortions in the calculated particle positions were observed. In previous work, the waveforms from the detector after preamplification were studied in detail to better understand the features that give rise to these distortions, where a waveform analysis technique was developed to improve the energy resolution and linearity in position reconstruction. However, the reading and writing of waveforms for an entire detector array greatly limits data collection rates and adds significant overhead in data storage and analysis speed. In this work, the integrators of a Struck SIS3316 ADC were utilized for ^{228}Th source data to develop and optimize a new analysis method that captures the benefits of the waveform analysis technique while circumventing the waveform writing requirement. This integrator method was used in the collection of 35 MeV/u ^{28}Si + ^{12}C collision data using FAUST for the study of particle-unbound excited states. With the non-linearity in position reconstruction largely removed, the impact of the energy-dependent DADL position resolution emergent from electronic noise on the quality of excited state measurement was modeled and compared to the experimental data.

Abstract 250 TUE-SN-STDS-02-1 Contributed Talk - Tuesday 10:00 AM - Pioneer IV

Repairing of Rust Induced Vacuum degradation of a Switching Magnet Chamber

Mohin Sharma, Mritunjaya Parashar, Todd A. Byers, Darshpreet Kaur Saini, Bibhudutta Rout, Gary A. Glass

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The Ion Beam Laboratory (IBL) at the University of North Texas contains four ion accelerators with dedicated beamlines for many ion beam modification and analysis techniques. The four accelerators include a 3 MV NEC tandem accelerator, a 3 MV NEC single-ended accelerator, a 2.5 MV single-ended Van de Graaff accelerator, and a 200 keV Cockcroft-Walton accelerator, which allows for a wide range of ion energies from 10 keV to over 15 MeV. The NEC 9SDH-2, 3-Million Volt Pelletron® tandem accelerator is equipped with two Sputter-Type Ion Sources and a Helium ion source. Essentially any element in the periodic table can be produced and accelerated to a terminal potential up to 3 MeV. The tandem accelerator has a Mass × Energy Product = 500 heavy-ion analyzing magnet and an eight-port switcher magnet. The switcher magnet installed was made by High Voltage Engineering in 1960. The pole faces of the switching magnet are enclosed inside vacuum chamber housing. Due to flooding that happened in the summer of 2017, there were issues with the magnet chamber not holding enough vacuum (less than 10^{-5} torr) and some rusting was seen beneath the coils. In this presentation, we will be discussing the maintenance work performed to restore the magnet chamber to its optimum vacuum condition.

Abstract 211 TUE-SN-STDS-02-2 Contributed Talk - Tuesday 10:00 AM - Pioneer IV

Calculating Charge State Distributions of Beams Accelerated by Tandem Accelerators

Barney L. Doyle

Sandia National Labs, Albuquerque NM, United States

One of the most important decisions that must be made before obtaining an energetic ion from a tandem-style accelerator is what charge state of the ions stripped of electrons in the terminal to use. Usually, the end-user of the ions doesn't really care about this charge state, so the accelerator technologist is free to select the charge state easiest to use, i.e. provides the highest particle current.

In 1977, Royce O. Sayer, a nuclear theorist at ORNL, did a great service to our SNEAP community by developing semi-empirical formulas for the stripping of heavy ions in C foils and gas (R.O. Sayer, Rev. de Phys. App. 12 (1543) 1977). I joined Sandia National Labs that same year and developed a program in the language TIL that ran on a Tennecomp multi-parameter MCA data acquisition system that used a PDP-11/34 DEC 32K computer. That program has evolved over the past 45 years and currently exists in 3 forms programmed in EXCEL with VBA macros:

Calculating the charge state distribution of all ions for both foil and gas terminal stripping with the input parameters: Z, M, Terminal Voltage.

Calculating the optimum (i.e. the highest current) charge state and terminal voltage with the input parameters: Z, M, E, Maximum Terminal Voltage.

Calculating the charge state distribution of ions stripped in the terminal and then further stripped in the residual gas between the high energy end of the tandem and the first analyzing or switching magnet and the field in that magnet to steer each beam to the endstation. The optimize program above is used to obtain the best terminal voltage.

The use of the first two is obvious but not the last one. We discovered at SNL in the IBL that when a very high energy heavy ion from the tandem is required, that a corresponding high charge state needs to be selected at the terminal. Because of this high charge state, the beam current of such an ion is very low. Other beams with different energies are also accelerated to the high energy end of the tandem that can be further stripped in the residual gas prior to the first magnet. While this further stripping is usually improbable, it can create beams with nearly the same mass-energy/q2 product as the desired high energy and highly charged ion, making separation by the magnet difficult. We have found these post-stripped beams even focus the same in our microbeam, and therefore contaminate such beams when performing radiation effects microscopy. This third program identifies such conflicts.

The following is a link to these and other programs.

https://www.sandia.gov/research/research-foundations/materials-science/facilities/ion-beam-modification/ion-beam-analysis/

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Abstract 123 TUE-SN-STDS-02-3 Contributed Talk - Tuesday 10:00 AM - Pioneer IV

Laser-assisted negative ion production in caesium sputter negative ion source

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The negative ion formation in the caesium sputter ion sources occurs on the surface of a cathode containing the ionized material. The cathode is covered by a thin layer of caesium (Cs), which lowers the work function of the surface enhancing the negative ion formation. Vogel [1] recently introduced a hypothesis that the negative ion current can be enhanced by exposing the cathode to a laser beam. According to [1] this should resonantly excite neutral caesium atoms to electronic states, acting as a catalyst for negative ion production via so-called ion pair production. Recent experiments at the JYFL-ACCLAB have revealed that the photo-assisted production of negative ions can be provoked by possibly any external laser with the photon energy exceeding a certain threshold, which questioned the resonant ion pair production hypothesis (2)Furthermore, the laser-assisted production of negative ions of oxygen (O^-) as well as aluminium (Al^-) was observed with the off-resonance diode lasers (3)This observation opens the door for practical applications of photo-assisted negative ion production also for other negative ion species, not just those with their electron affinity states in resonance with the excited states of neutral Cs. Figure 1 (a), (b) shows the laser assisted effect on the O^- beam currents with three different laser wavelengths, and powers, at 50 s and 100 ms laser pulses respectively (2)Figure 1 (c) shows the example of laser-assisted beam current enhancement result obtained with 445 nm, 6 W diode (2)In this presentation we introduce newest results and corresponding qualitative explanation for the laser-assisted effect. Finally, we discuss plans to optimize the laser optics, first in an off-line test bench, as in the previous experiment the maximum laser power delivered to the cathode was only 80 mW (now up to 600 mW) out of 6 W (now 15 W) available from the diode laser. Our future plans include testing the method with other, high-performance, caesium sputter ion sources to develop a "turn-key" laser booster for SNICS sources.

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Abstract 194 TUE-AA-IBTM-03-1 Invited Talk - Tuesday 12:30 PM - Kincaid (Hybrid)

Sequential molecular and elemental imaging on a single tissue section using DESI and PIXE

Catia Costa[1], Janella de Jesus[1,3], Chelsea Nikula[3], Josephine Bunch[3], Geoffrey Grime[1], Veronique Dartois[4,5], Kaya Firat[5], Vladimir Palitsin[1], Roger Webb[1], Melanie Bailey[1,2]

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Elemental and molecular imaging play a crucial role in understanding disease pathogenesis but are rarely used in combination. However co-localising elements and metabolites is important to biologists understanding the impact of metallic impurities or bioaccumulated metals on the host. To accurately correlate elemental and molecular markers, it is desirable to perform sequential elemental and molecular imaging on a single-tissue section. However, very little is known about the impact of performing these measurements in sequence.

In this presentation, we highlight some of the challenges and successes associated with performing elemental mapping in sequence with mass spectrometry imaging. Specifically, the feasibility of molecular mapping using the mass spectrometry imaging (MSI) techniques matrix-assisted laser desorption ionization (MALDI) and desorption electrospray ionization (DESI) in sequence with the elemental mapping technique particle-induced X-ray emission (PIXE) is explored. Challenges for integration include substrate compatibility, as well as delocalization and spectral changes. We demonstrate that, further to our published work [1], delocalisation of trace elements can be mitigated through adaption of the DESI method. This allows sequential DESI-PIXE imaging without any compromises to either the DESI or PIXE spectra. This approach will enable research into the impact of metal accumulation to the host metabolism in tissues and should be of broad interest in the biosciences.

[1] Janella Marie de Jesus, Catia Costa, Amy Burton, Vladimir Palitsin, Roger Webb, Adam Taylor, Chelsea Nikula, Alex Dexter, Firat Kaya, Mark Chambers, Veronique Dartois, Richard J. A. Goodwin, Josephine Bunch, and Melanie J. Bailey; **Correlative Imaging of Trace Elements and Intact Molecular Species in a Single-Tissue Sample at the 50 µm Scale** Analytical Chemistry 2021 93 (40), 13450-13458

Abstract 233 TUE-AA-IBTM-03-2 Invited Talk - Tuesday 12:30 PM - Kincaid (Hybrid)

Application of multiple ion beam analysis techniques in plant biology and nutritional science

Bostjan Jencic[1], Paula Pongrac[1,2], Primož Vavpetič[1], Mitja Kelemen[1], Žiga Barba[1], Katarina Vogel-Mikuš[1,2], Marjana Regvar[2], Ivan Kreft[2], Primož Pelicon[1]

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Within the present work, we demonstrate the relevance of IBA techniques in plant biology. Information about the distribution of various nutrients within the biological tissue helps undestanding and solving several problems, including the loss and limited bioavailability of micronutrients during food processing protocols. Concentration of several elements and metabolites within the tissue also depends on several factors, from the amount of those elements in the surrounding soil, to altitude and exposure to UV radiation.

Complementary information on distribution of both micro and macro nutrients can be obtained by imaging techniques PIXE (Particle Induced X-ray Emission) and MeV-SIMS (MeV primary ion induced Secondary Ion Mass Spectrometry), which are utilized at the microanalytical center of Jožef Stefan Institute in Ljubljana, Slovenia . Although MeV-SIMS is still a developing technique, it offers great sensitivity to heavy biomolecules, while it can already match the lateral resolution of PIXE, which is below 1 μm. We have demonstrated such complementary analysis on Tartary buckwheat, a highly nutritional food, rich with both essential mineral elements, and active biomolecules.

Abstract 39 TUE-AA-IBTM-03-4 Contributed Talk - Tuesday 12:30 PM - Kincaid (Hybrid)

Colocation of Lipids, Drugs, and Metal Biomarkers Using Spatially Resolved Lipidomics with Ion Beam Elemental Mapping

Holly Lewis[1], Catia DS Costa[1], Veronique Dartois[2], Firat Kaya[2], Vladimir Palitsin[1], Mark Chambers[1], Roger Webb[1], Melanie J Bailey[1]

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Elemental imaging is widely used for imaging cells and tissues but rarely in combination with organic mass spectrometry, which can be used to profile lipids and measure drug concentrations. Here, we demonstrate how ion beam elemental imaging (PIXE and RBS) and a new method for spatially resolved lipidomics (DAPNe-LC-MS, based on capillary microsampling and liquid chromatography mass spectrometry) can be used in combination to probe the relationship between metals, drugs, and lipids in discrete areas of tissues. This new method for spatial lipidomics, has been applied to rabbit lung tissues containing a lesion (caseous granuloma) caused by tuberculosis infection. We demonstrate how IBA with spatially resolved lipidomics can be used to probe the association between ion accumulation and lipid profiles and verify local drug distribution.

Abstract 127 TUE-AP-TA-02-1 Invited Talk - Tuesday 12:30 PM - Pioneer III

Probing nuclei with neutrons at UKAL through research designed to maximize student contributions and collaborations

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[(5)]Physics and Astronomy, Mississippi State University, Starkville MS, United States

The University of Kentucky Accelerator Laboratory (UKAL) has served for almost sixty years as a facility to educate undergraduate and graduate students, as well as postdoctoral fellows, on the intricacies of probing nuclei with neutrons. The focus of student doctoral dissertations, as well as undergraduate research theses, typically falls within two main categories: nuclear structure or neutron scattering. Most recently nuclear structure studies have focused on the investigation of the properties of parent and daughter nuclei important for neutrinoless double beta decay studies or the measurement of

neutron elastic and inelastic scattering cross sections important for energy production, homeland security and medical applications, respectively. The laboratory has recently implemented a digital data acquisition system that offers students new opportunities for investigating how neutrons interact with nuclei in the fast neutron region. Examples of research projects and student career trajectories will be presented. UKAL is a member of the Association for Research at University Research Accelerators (ARUNA).

Research is funded by DOE grants SC0021424, SC0021243, SC0021175, SSC000056 and NSF grants PHY - 1913028 and PHY - 2209178.

Abstract 27 TUE-AP-TA-02-2 Contributed Talk - Tuesday 12:30 PM - Pioneer III

Developing a Remote Gamma Spectra Collection System for Radiation Sciences at the University of Nevada Las Vegas

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The interruption of experimental activities during the pandemic causes suffering to students and professors, particularly for these experiments involving radiation detection and measurement. Most of the experiments for teaching have been temporarily suspended due to the social distance policy and the constrained capacity of the facilities. To address this challenge, we established a remote spectra collection system to allow students to receive gamma spectra online and remotely operate the automatic sample changer with robotic sample handling. The project served as a platform, especially for minority students, for studying software design, data acquisition, instrumental control, and prototype testing in real-time scenarios. The project improves educational and research endeavors via the campus network, diminishes the needs of laboratory personnel, and significantly reduces the cost of education. It assists students in successfully finishing their degrees on schedule in nuclear sciences during the pandemic.

Abstract 128 TUE-AP-TA-02-3 Invited Talk - Tuesday 12:30 PM - Pioneer III

Teaching a Graduate-Level Ion Beam Course at the Louisiana Accelerator Center

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In 1991, a National Electrostatic Corporation 1.7 MV 5SDH-2 tandem Pelletron® accelerator was installed at the Louisiana Accelerator Center (LAC) at the University of Louisiana at Lafayette (UL Lafayette). This machine is designed to accelerate beams of ions from protons to lead with energies of less than 3.4 MeV/u. Currently, there are three high-energy transport experimental end stations: 1) Micro-beamline, 2) Ultra-low flux biosafety level-2 beamline, and 3) Implantation beamline. In 2001, an ion microprobe system from Oxford Microbeams (OM) was installed and first utilized with funding from the state of Louisiana. Recently, efforts were started to computerize the control system for the 5SDH-2 Pelletron using NEC AccelNET. This upgrade was a result of another successful $475,000 grant from the state of Louisiana. One of the goals for this new grant was to utilize LAC equipment in courses offered by UL Lafayette.

For most of its history, research at LAC has concentrated on a variety of topics, including the development of high-energy ion beam microscopy systems and techniques, measuring trace element concentrations in environmental and biological samples, and other similar related topics. Since the Pelletron was installed, it has been used for a variety of student/faculty projects, student theses/dissertations, and general research programs for a variety of government and private customers. One important aspect of this work has been in the realm of education and training. Since it was first installed, faculty and staff from UL Lafayette has used the Pelletron as a teaching tool in a variety of STEM courses, including first year physics, modern physics, nuclear physics, space physics/engineering, vacuum pumps/practice, electronics, machine shop practice

and metallurgy, and other related topics. Graduate courses in ion beam physics, nuclear physics in extreme environments, vacuum pumps/practice have also been given. Tours of LAC for groups like the girl/boy scouts, campus clubs, prospective new students, and the public are commonly given. It is a common practice for graduate students to be trained to operate the Pelletron as they use it for their research. Education is an important foundation to all research completed at LAC.

Until recently, faculty from the UL Lafayette Department of Physics has offered two courses in Ion Beam Methods and Nuclear Microscopy at LAC. Both courses are both listed as PHYS 521 in the UL Lafayette catalog. These courses ware offered in alternating years for advanced undergraduate and graduate level students. The Ion Beam Methods course gives students an understanding of the physical principles for ion beam interactions, including hands-on experience with advanced techniques such as PIXE, RBS, STIM, ion implantation, and vacuum technology. In addition, students complete a short research project that gives them hands-on experience with ion beam technology. The Nuclear Microscopy course reviews the detailed physics of nuclear microprobes and how they can be used for micron-scale PIXE, RBS, STIM, and ion implantation. For the last few years, these two courses have been merged into one PHYS 521 course called Ion Beam Methods, since LAC now has two working microprobe experimental end stations. This new revised PHYS 521 course provides students with technical information about accelerators, ion sources, beam diagnostic equipment, understanding of accelerator-based radiation safety, accelerator hazard awareness and mitigation, automation of accelerators, detection electronics, and the application of electrostatic accelerators and related systems. This course combines lectures with experiments to be performed at LAC in the post-accelerator beamlines. This course meets one afternoon each week for 2.5 hours.

The propose of this presentation is to discuss the depth and structure of the UL Lafayette PHYS 521 Ion Beam Methods class that is being taught at LAC during fall 2022. Emphasis will be placed on the presented course material as well as a description of some of the data collected by the students each week. Students who complete this course are ideally suited to work in labs like LAC for their thesis/dissertation projects in the future.

Abstract 144 TUE-AR-NST-02-1 Invited Talk - Tuesday 12:30 PM - Arabian

Coherent Optical Spectroscopy Studies of Hidden Silicon-Vacancy Centers in Diamond

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Negatively charged silicon-vacancy (SiV^-) centers in diamond, which can be generated in diamond substrates by means of ion implantation followed by annealing and cleaning protocols, comprise a promising material system for use in quantum networks and devices. In the effort to capitalize on this potential, several research groups have made progress in recent years aimed at controllably generating individual SiV^- centers at well-defined locations, and then precisely manipulating their properties once generated. In spite of these advances, open questions remain connected to the underlying electronic structure of the SiV^- center system, to the way that this structure is affected by strain, and to the way that SiV^- centers behave when situated in densely packed ensembles.

In this talk, I will discuss some of the progress that has been made in understanding the material properties of SiV^- centers at a fundamental level, reporting on measurements using the technique of optical multidimensional coherent spectroscopy (MDCS) to investigate a high-density ensemble of SiV^- centers in bulk single-crystal diamond. By comparing photoluminescence (PL)-based and heterodyne-detection-based MDCS signal collection schemes, we are able to selectively distinguish between luminescing and nonluminescing color centers. Somewhat surprisingly, we observe a large population of SiV^- center transitions that are typically hidden (i.e., not observed) under PL detection, and which have more than 60 times as much inhomogeneous spectral broadening as the population of PL-emitting "bright" states. A detailed comparison of homogeneous dephasing rates reveals longer T_2 electronic coherence times for the hidden population as compared to the bright population, indicating that electronic dephasing interactions in the hidden population are diminished.

By characterizing the amount of inhomogeneous broadening and conducting quantitative computational simulations, we argue that the most likely source of the inhomogeneity and extended T_2 times of the hidden population is inhomogeneous strain, and we discuss mechanisms by which strain and electronic dephasing might be linked. The results exemplify the

power of MDCS as a tool for characterizing color center materials, and they inform the development of strain-utilizing color center devices and applications.

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Abstract 154 TUE-AR-NST-02-2 Invited Talk - Tuesday 12:30 PM - Arabian

Measuring Strain and Coherent Interactions in an Ensemble of Silicon-Vacancy Centers in Diamond

Kelsey M. Bates[1], Matthew W. Day[1,2], Christopher L. Smallwood[3], Rachel C. Owen[1], Tim Schröder[4], Edward Bielejec[5], Ronald Ulbricht[6], Steven T. Cundiff[1]

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[(5)]Sandia National Laboratories, Albuquerque NM, United States
[(6)]Max Planck Institute for Polymer Research, Mainz, Germany

Color centers in diamond are point defects in the diamond lattice that have shown potential in a variety of quantum information and sensing applications, including as room temperature qubits and microscopic magnetometers. The silicon-vacancy (SiV^-) center is one such defect, consisting of a negatively charged silicon atom located between two adjacent vacant lattice sites. Unlike the more studied nitrogen-vacancy (NV^-) centers, SiV^- centers are inversion symmetric, protecting them from linear perturbations, and have a stronger zero phonon line compared to the NV^- center [1].

Here, we used several spectroscopic techniques to investigate an ensemble of SiV^- centers to measure the full strain tensor in our sample, and to observe dipole-dipole interactions between nearby centers. Our primary and most powerful technique was photoluminescence detected collinear multidimensional coherent spectroscopy (MDCS) (2)This technique uses the third-order nonlinear response of the sample. We employed both rephasing and two-quantum variants. Linear two-pulse correlation (TPC) spectra were also taken with small modifications to the experimental setup. We used a chemical-vapor deposition grown diamond sample, which was implanted with Silicon-29 ions and annealed. All data were taken at cryogenic temperatures.

To measure the strain in our sample, a combination of rephasing MDCS and TPC spectra were used, since rephasing MDCS excels at unfolding complicated spectra, such as those of our sample, while TPC is a simpler and faster measurement. After identifying the many observed spectral peaks and associating them to different SiV^- orientation groups, we solved for the full strain tensor in the sample. The collinear design of the experiment enabled a laser spot size small enough for position dependent measurements, but large enough to measure the spectra and strain of an ensemble of SiV^- centers. As no strain was intentionally applied, the source of strain is likely due to the high implantation density of our sample [3].

To measure interactions between nearby SiV^- centers, we used two-quantum MDCS. This MDCS variant involves a coherence between ground and doubly excited states. For the SiV^- center the doubly excited state must come from interacting centers, thus any two-quantum MDCS signal is a background-free measurement of these interactions. Adding a pulse of variable power before the MDCS pulses revealed oscillations of some two-quantum MDCS spectral peaks. Thus varying the strength of the pre-pulse allowed the tuning of the interaction strength between nearby SiV^- centers [4].

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Abstract 148 TUE-AR-NST-02-4 Invited Talk - Tuesday 12:30 PM - Arabian

Effects of Ion Implantation Damage on Photoluminescence of Silicon-Vacancy Centers in Diamond

Stephen Revesz[1], Hebin Li[1], John B.S. Abraham[2,3], Edward S. Bielejec[3], Michael Titze[3]

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One method for creating silicon vacancy (SiV) color centers in diamond is by focused ion beam implantation. This deterministic approach allows investigation of implantation damage at different ion beam fluence without sample-to-sample differences being a factor to consider. Ten stripes of SiV color centers were implanted in an electronic grade diamond substrate (1 ppb nitrogen impurities) with fluences ranging from 10^{10} to 10^{17} ions/cm^2 in steps of one order of magnitude. The optical properties of implanted color centers for each fluence were investigated by exciting each region with a 532-nm continuous-wave laser and sending the photoluminescence to a spectrometer. Of particular interest were the broadening dynamics as a function of fluence and the phonon side-band behavior at different temperatures. The diamond sample was placed in a closed-cycle liquid helium cryostat and cooled to 4 K for low temperature characterization. At cryogenic temperatures the doubly split excited state was observed (~250 GHz) but the doubly split ground state (~40 GHz) was inaccessible due to the spectrometer resolution. The linewidths, center wavelengths, and area of the resonances were used as indicators to characterize the optical properties. It was found that the optical properties are largely unaffected by the damage of the environment up to the graphitization threshold. The unaffected optical properties due to lattice damage suggests higher fluence electron beam irradiation can be a viable technique for increasing SiV yield while being performed at greater temperatures to minimize graphitization.

Abstract 209 TUE-AR-RE-02-1 Invited Talk - Tuesday 12:30 PM - Quarter

Beam-On Effects in Nuclear Materials for Generation IV Fission and Fusion Reactors

Weiyue Zhou[1,2], Kevin B Woller[2], Guiqiu (Tony) Zheng[3], Nouf M AlMousa[1,6], Peter W Stahle[2], Yang Yang[4], Andrew M Minor[5], Alexis Devitre[1,2], David Fischer[2], Zachary S Hartwig[1,2], Dennis G Whyte[1,2], Michael P Short[1,2]

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Nuclear materials by definition must remain robust in highly coupled environments, where high temperatures, plasmas, stresses, magnetic fields, and corrosion will all co-exist with irradiation. Developing useful nuclear materials and predicting their failure modes therefore must rely on well-controlled experiments with as many of these coupled variables as possible. In the race to deploy advanced fission and fusion nuclear reactors to increase the supply of carbon-free power for the world,

testing and predicting materials performance in their full, coupled environment, including simultaneous irradiation, is necessary before confidently deploying these energy systems. However, it is quite difficult to perform such tests, leaving a huge knowledge gap about our knowledge of candidate materials and how they will actually perform in advanced nuclear systems. In addition, without atomistic insights into the mechanisms and extents of such beam-on effects, it will be too difficult to predict their effects in yet-untested environments.

In this talk, we will explore two such ongoing examples, which are pushing nuclear materials discovery to the speed of thought. In some cases radiation acts as an unexpected healing force for structural materials, while in other cases not properly accounting for radiation's coupled effects would be absolutely disastrous for system design and reliability. This talk will therefore both challenge our commonly-held assumption that radiation effects often reduce to "bad news," while also showing us that not accounting for their coupled effects may seriously hamper advanced reactor deployment.

First comes our discovery of irradiation-slowed corrosion in certain cases in molten salts, not previously seen when separating the irradiation and corrosion processes. We show that radiation makes good alloys perform better, and bad alloys perform worse. A combination of **in situ** experiments and atomistic simulations both reveals and explains why, and in wihch circumstances, radiation can slow corrosion. Second is a new discovery that high temperature superconducting magnets, critical to fusion reactor operation, degrade in performance only while irradiation is actively occurring, which was never observed before. The seemingly small decrease in critical current (I_c) of 10%, because it is scaled to the 30^{th} power, results in a 17x higher magnet power dissipation, potentially device-killing if not properly accounted for by higher magnet design margins. Atomistic simulations help reveal which defects may be responsible for the increase of I_c following irradiation, and which others may be responsible for the decrease in I_c during irradiation. Insights learned specifically from the simultaneous coupled effects will be the focus of this talk.

Abstract 202 TUE-AR-RE-02-2 Invited Talk - Tuesday 12:30 PM - Quarter

Elucidating the interactions between Hydrogen/Helium with extended defects in Tungsten: An atomic-scale perspective

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Tungsten (W) is considered to be the primary candidate for divertor in future fusion reactors. Retention from fuel and nuclear transmutation reactions lead to formation of H and He in the divertor. These species may cluster together and their interaction with extended defects, such as dislocations and grain boundaries, span a wide range of phenomena such as 'pipe-diffusion', obstacle strengthening, grain boundary (GB) pinning etc. These can have important ramifications on the retention of H/He gas, and evolution of microstructure and mechanical properties of the W divertor, especially during transient thermal loads. Predictions from molecular dynamics simulations on the interactions between H/He with dislocations and symmetric-tilt GBs will be discussed. Mechanisms for pipe-diffusion are found to vary between screw and edge dislocations and also on the type of interstitial. Segregation of H to GBs results in a complex, structure-dependent effect on GB mobility. Assuming a disconnection-based mechanism for GB motion, it is shown that the conventional picture of solute-drag dominated Arrhenius kinetics is incomplete and these results will be discussed in the context of recrystallisation. Ramifications of He-bubble growth in the vicinity of dislocations which, in turn, leads to complex reactions with the existing dislocation and modification of its character will also be discussed.

Abstract 189 TUE-AR-RE-02-3 Invited Talk - Tuesday 12:30 PM - Quarter

Current and future advances in plasma-facing materials and experimental facilities to enable nuclear fusion

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The plasma-material interface in nuclear fusion reactors represents one of the harshest environmental service conditions for materials, exposing them to 14 MeV neutron bombardment, low energy deuterium (D) and helium (He) bombardment, steady state temperatures above 400°C and transient heat fluxes >1GW/m^2. Currently, tungsten (W) is proposed as the plasma-facing material of choice for its high-Z nature, high melting point, and low H retention properties. However, W is inherently brittle, is further embrittled under irradiation, and develops undesired surface nanostructures under He irradiation. Numerous strategies have been employed to improve the performance of W in a fusion reactor setting, including changing the grain size [1], alloying [2], layering [3], and introducing second phase particles (4)This talk will highlight developments in tungsten, including nanocrystalline W, dispersion-strengthened W, refractory complex concentrated alloys, and additively manufactured refractory alloys. Walking through processing of materials from spark plasma sintering and laser additive manufacturing, to experiments in facilities designed for fusion materials investigations, this talk will describe advances in understanding materials microstructure and evolution with accelerator techniques. This work will focus on experimental advances in understanding of material evolution in the extreme nuclear fusion reactor environment, especially in the realm of **in situ** experimentation and characterization of materials under He irradiation, high temperatures (>800°C), and mechanical stress coupled to accelerators. Experimental facilities and microstructures bridging the nano- to micro-scales will be emphasized, including the **in situ** ion irradiation TEM (I^{3}TEM) [5] and newly-designed **in situ** ion irradiation SEM (I^{3}SEM) at Sandia National Laboratories. This work will highlight the advances of W regarding He management, microstructure stabilization, and advanced manufacturing and discuss further challenges and experiments needed to design and qualify advanced materials for use in a fusion environment.

This work was performed at the Center for Integrated Nanotechnologies, an Office of Science User Facility operated for the U.S. Department of Energy (DOE) Office of Science. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525.

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Abstract 252 TUE-PR-SP-04-1 Invited Talk - Tuesday 12:30 PM - Palomino

Application of sensitive laser spectroscopy techniques in mass spectrometry

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The limit of detection of mass spectrometry techniques such as ICP-MS is often determined by the presence of intense inference species. A similar challenge is also encountered at on-line facilities that use the ISOL production method. In both cases this has limited the reach for many studies by obscuring the detection of the isotope of interest. We have developed the Collinear Resonance Ionization Spectroscopy (CRIS) method at ISOLDE CERN to overcome this barrier. The original goal was to extend high-resolution laser spectroscopy measurements to the most exotic nuclei with production rates of less than 1 atom per second. The technique combines high detection efficiency, high specificity, extremely low background

rates and almost universal applicability across the periodic table. We have demonstrated the ability to reduce the intensity of a contaminant beam by more than seven orders of magnitude, while still efficiently detecting the species of interest. This enabled measurements of exotic systems such as ^{52}K, ^{78}Cu, ^{131}In [1,2,3].

This approach of interference suppression has applications beyond fundamental science when combined with existing mass spectrometry tools such as isotope ratio mass spectrometry (IRMS) and inductively coupled mass spectrometry (ICP-MS). Extending the current limit of detection of these techniques has the potential to enable analysis previously the domain of other techniques, such as the detection of cosmogenic isotopes in environmental samples. In particular this will allow ICP-MS to be used to detect 90Sr in the environment and help reduce the costs and timescales associated with low level waste characterization. This talk will present the development and commercialization from ISOLDE towards a laser-based mass spectrometer for trace isotope detection and the associated commercialization project at the University of Manchester.

[1] Á Koszorús et al. Nature Physics 17 439-443 (2021)

[2] RP de Groote et al. Nature Physics 16 620-624 (2020)

[3] AR Vernon et al. Nature 607, 260-265 (2022)

Abstract 37 TUE-PR-SP-04-2 Invited Talk - Tuesday 12:30 PM - Palomino

Laser spectroscopy developments at IGISOL

Mikael Reponen[1], Iain Moore[1], Tommi Eronen[1], Ruben de Groote[2], Ágota Koszorús[3], Andrea Raggio[1], Sonja Kujanpää[1], Alejandro Ortiz-Cortes[4]

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The IGISOL facility has been actively involved in nuclear physics research for over three decades (1)The facility utilizes beams from a K-130 cyclotron to produce low-energy ion beams for nuclear ground-state studies. The main fields of research are precision Penning-trap -based mass measurements and trap-assisted decay spectroscopy, collinear laser spectroscopy, and development of in-source laser spectroscopic methods and instruments.

On the precision laser spectroscopy frontier, the collinear laser spectroscopy line has been upgraded with a new charge exchange cell and light collection region. The upgraded setup has been used for the spectroscopy of Pd [2], Ag [3], and in the past months, Co, and Fe. Furthermore, the CRIS method, originating from ISOLDE, CERN, has been implemented at IGISOL at the RAPTOR setup. The setup is under commissioning with successful offline demonstrations on Cu and Sn.

The advances in Penning trap techniques have enabled ultra-sensitive Phase-Imaging Ion-Cyclotron-Resonance (PI-ICR) assisted in-source RIS (4)This technique combined an inductively heated hot cavity catcher laser ion source. This novel technique was used to cross the **N**=50 shell closure near ^{100}Sn for the first time with the charge-radii measurement of ^{96}Ag. Since then, the measurements have been extended to ^{95}Ag, with the immediate goal being a direct mass measurement of ^{94}Ag. The utilization of the setup for producing proton rich Pd, Cd, In and Sn is also being investigated.

In addition, two further research stations utilizing optical techniques are in operation at IGISOL, expanding the scientific scope of the facility. The first, operated by University College London, is an atom trap aiming to create a BEC of radioactive caesium with the aim for a coherent emission via the simultaneous decay of ^{135m}Cs isomer (5)The second is the MORA (Matter's Origin from the RadioActivity of trapped and oriented ions) [6] setup, aiming at measuring the D correlation in nuclear beta decay utilizing trapped and laser polarized ions.

In this presentation we will discuss the recent results, the near future aims, as well as the future expansion of the hot cavity activities, involving fission products and long-lived isotopes.

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[2] S. Geldhof et al., "Impact of Nuclear Deformation and Pairing on the Charge Radii of Palladium Isotopes," Phys. Rev. Lett, vol. 128, no. 152501, 2022.

[3] R. P. de Groote and et al., "Measurements of binding energies and electromagnetic moments of silver isotopes - a complementary benchmark of density functional theory," Submitted to Phys. Rev. Lett., 2022.

[4] M. Reponen et al., "Evidence of a sudden increase in the nuclear size of proton-rich silver-96," Nat. Comm., vol. 12, no. 4596, 2021.

[5] L. Marmugi, P. M. Walker, and F. Renzoni, "Coherent gamma photon generation in a Bose-Einstein condensate of 135mCs," Phys. Lett. B, vol. 777, pp. 281-285, 2018.

[6] P. Delahaye et al., "The MORA project," Hyp. Int., vol. 240, p. 63, 2019.

Abstract 83 TUE-PR-SP-04-3 Invited Talk - Tuesday 12:30 PM - Palomino

The novel way of Optical Spectroscopy towards the Super Heavy Elements: Laser Resonance Chromatography

Elisa Romero Romero[1,2,3], Michael Block[1,2,3], Biswajit Jana[1,2,3], Eunkang Kim[1,2,3], Steven Nothhelfer[1,2,3], Sebastian Raeder[2,3], Harry Ramanantoanina[1,2,3], Elisabeth Rickert[1,2,3], Jonas Schneider[1], Philipp Sikora[1], Mustapha Laatiaoui[1,2,3]

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In the last two decades, there have been outstanding efforts in the discovery and study of the superheavy elements (SHEs). However the experimental access to these short-lived atomic species is very challenging as they are produced in nuclear fusion reactions at rates of only a few atoms per second at most. Furthermore, some of these elements are predicted to not behave chemically like their lighter homologs, with relativistic effects being the dominant cause of this peculiarity (1)At present, in-gas-cell laser resonance ionization spectroscopy (RIS) is the most advanced method for atomic structure studies on the heaviest elements, with nobelium (No, atomic number Z= 102) being the last element investigated using this technique (2)For elements beyond nobelium, only predictions of the atomic structure exist. Typically, RIS techniques require neutralization, creating limitations towards the SHE research. In this talk I will introduce the new technique of Laser Resonance Chromatography [3] for SHEs studies. This technique combines resonant laser excitation with electronic-state chromatography [4] and is conducted directly on the ion in-situ, without the need for a neutralization step, using only one laser of a proper wavelength to optically pump the ions into a metastable state from the ionic ground state. I will present initial experiments with electronic state chromatography on Cu+ and Lu+ and ion trajectory simulations on Sc+.

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 Research and Innovation Programme (Grant Agreement No. 819957).

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[3] Laatiaoui, M.et al. Phys. Rev. Lett. 2020, 125, 023002.

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Abstract 115 TUE-PR-SP-04-4 Contributed Talk - Tuesday 12:30 PM - Palomino

Investigating Low Energy Heavy-Ion Response of sCVD Diamond Detectors

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Single-crystalline chemical vapor deposition (sCVD) diamond detectors have been used extensively in high-energy research due to their good energy and timing resolution and for their superior radiation hardness when compared to silicon. However, some evidence indicated that these properties were not as favorable for low energy heavy-ion beams. Various sCVD diamond detectors were studied at the Texas A&M University Cyclotron Institute to investigate the energy and timing resolution, the radiation hardness, the pulse-height defect (PHD) and other effects at various rates (10-1200 particles per second) of low energy (< 50 MeV/u) heavy ions (> ^{4}He). Three separate tests were performed: the first utilized a 20 μm - 500 μm diamond telescope to measure the reaction products of a 20 MeV/u ^{20}Ne beam on a ^{12}C target to assess isotopic resolution, the second involved testing the simultaneous energy and timing resolution of the same 20 μm - 500 μm diamond telescope using the alpha particles from a ^{228}Th source, and the third placed a different 20 μm diamond detector in direct beam of 7.5 MeV/u ^{78}Kr at varying beam rates to test radiation hardness. Evidence of polarization was observed and permanent damage was characterized after an accumulated dose of 6.9x10^{8} ^{78}Kr by comparing energy resolution achieved before and after the test. The pulse-height defect was also monitored. The combination of these three tests allowed us to investigate the intrinsic energy and timing resolution of the diamond detectors before testing the radiation hardness and response to low energy heavy-ions. The observations of isotopic resolution, permanent damage, polarization, and a PHD will be discussed.

Abstract 169 TUE-SN-SSR-02-1 Contributed Talk - Tuesday 12:30 PM - Pioneer IV

Status report of CAMS and SSAMS at CAIS, University of Georgia

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The Center for Applied Isotope Studies at the University of Georgia has two compact accelerators for Accelerator Mass Spectrometry (AMS) of radiocarbon. The NEC made 500 kV 1.5SDH-1 tandem pelletron (CAMS) has been in operation over 20 years whereas the NEC 250 kV single stage accelerator (SSAMS) has been in operation for over 10 years. The AMS facility accepts samples from academic researchers as well as the industry, and analyzes over 10000 samples annually. We will discuss the characteristics and performance of the instruments, issues and troubleshooting.

Abstract 152 TUE-SN-SSR-02-2 Invited Talk - Tuesday 12:30 PM - Pioneer IV

Upgrading IVEM Tandem Accelerator at Argonne National Laboratory

Josh Hlavenka[1], Dzmitry Harbaruk[1], Pete Baldo[2], Wei-Ying Chen[2], Meimei Li[2], Sergey Chemerisov[1]

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The Intermediate Voltage Electron Microscopy (IVEM) - Tandem facility at Argonne National Laboratory is a dual-ion beam facility that can accommodate both in-situ and ex-situ irradiation studies of defect structures. This facility is unique in its ability to record real-time video of the defect formation during irradiation under well-controlled experimental conditions including ion type, ion beam energy, dose rate, dose, sample temperature, sample orientation, and applied strain. The IVEM-Tandem Facility manages 2 accelerators, a 500 kV NEC Cockroft-Walton ion implanter and a 2 MV NEC Tandem accelerator. Recent efforts to expand our ex-situ capabilities will require improvements to the tandem accelerator, here we will present our plans to upgrade the tandem accelerator.

Abstract 118 TUE-SN-SSR-02-3 Contributed Talk - Tuesday 12:30 PM - Pioneer IV

Brookhaven National Laboratory Tandem Van de Graaff Facility

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The Brookhaven Nation Laboratory (BNL) Tandem Van de Graaff facility consists of the two largest operating Tandems (MP6 and MP7) in North America with a terminal voltage of over 14 MV. They deliver a wide variety of ions (from protons to gold) to outside users on a full cost recovery basis. The 55-degree east beam line is used for Single Event Upset (SEU) testing of electronics, detector calibration, ion irradiation and other space-related and industrial applications. The 65-degree west beam line is used for the production of micro-pore filter material but has been modified to allow the high energy ion implantation of Silicon Carbide (SIC) wafers as well. The beam line is being further upgraded to heat the SiC wafers to high temperature during the implantation process. Recent upgrades to the safety systems will also be discussed.

Abstract 20 TUE-SN-SSR-02-4 Contributed Talk - Tuesday 12:30 PM - Pioneer IV

Update on the Woods Hole Oceanographic Institution's Accelerator Mass Spectrometry Systems

Mark Roberts[1], Brett Longworth[1], Taylor Broek[1], Josh Hlavenka[2]

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[(2)]Experimental Operations and Facilities, Argonne National Laboratory, Argonne IL, United States

The National Ocean Sciences Accelerator Mass Spectrometry (NOSAMS) facility at the Woods Hole Oceanographic Institution operates two accelerator systems. Both systems are used exclusively for ^{14}C AMS. The first system is based on a 500 kV NEC Pelletron accelerator and incorporates both a 134-sample conventional graphite sputter source and a unique, gas-accepting, microwave ion source. The second system is an Ionplus MICADAS (MIni CArbon DAting System) that was installed in the spring of 2022. The MICADAS system replaced the 3 MV tandetron accelerator built by the US-AMS Corporation that was operational from 1991-2021 and decommissioned late last year. Status and operational experiences with both accelerator systems will be presented.

Abstract 276 TUE-AP-MA-02-1 Invited Talk - Tuesday 2:30 PM - Quarter

Adapting a fixed beam line for pre-clinical proton FLASH investigations

Eric Stanton Diffenderfer, Michele M Kim, Khayrullo Shoniyozov, Wei Zou, Rodney Wiersma, Keith Cengel, Lei Dong

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Ionizing radiation delivered at ultra-high dose rates (UHDR) has been associated with reduced normal tissue toxicity in small animal models when compared with radiation delivered at conventional dose rates. The effect on tumor control is found to be independent of dose rate when comparing UHDR with conventional dose rates in irradiated animal tumor models. This differential normal tissue response and iso-effective tumor response has been dubbed the FLASH effect. FLASH radiation could have a potentially profound effect on cancer treatment if the technology to deliver UHDR radiation can be translated and optimized for clinical use. To this end, we have developed and validated an instrument to deliver UHDR proton beams for preclinical research in small animal models using a research proton beam line on a clinical proton radiotherapy system. We have developed several subsystems to investigate and optimize clinically relevant delivery parameters in small animal models. Among these, a dose monitoring and beam control feedback system was developed to precisely deliver proton dose at UHDR and conventional dose rate. A scattering and beam collimation system was developed to create a symmetric and uniform field with high proton use efficiency for delivering relatively large fields to small animals at all dose rates. A ridge filter was designed, and 3D printed to efficiently modulate proton beam energy and create a spread-out bragg peak. Additionally, an animal scanning system synchronized with beam delivery was developed to investigate spatially and temporally varying dose delivery on the FLASH effect.

Abstract 223 TUE-AP-MA-02-2 Invited Talk - Tuesday 2:30 PM - Quarter

Electron FLASH Radiotherapy Platform: Characterization, Safety, and Validation

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[(4)]Dartmouth Cancer Center, Dartmouth-Hitchcock Medical Center, Lebanon NH, United States
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Ultra-high dose-rate (UHDR, >40Gy/s mean) FLASH radiotherapy can improve the therapeutic ratio as studies suggest there is reduced normal tissue toxicity, while providing new patient motion management strategies with reduced delivery time (<1s). The renewed interest in the modality lead to investigations on the underlying normal tissue sparing mechanisms and trials including large animals and humans but is faced with two gaps:

1. Lack of UHDR delivery technology for widespread implementation

2. Shortage of UHDR appropriate dosimetry and quality assurance (QA) tools for planning and confirming treatments

We hypothesized modifying current delivery and QA technology can consistently and accurately deliver prescribed dose under UHDR conditions with minimal changes to the clinical workflow for potentially increased accessibility. A readily available clinical LINAC was modified for UHDR electron beam delivery (>300Gy/s) at the isocenter with current clinical accessories and geometry. A team of clinical and research professionals identified methods to mitigate potential errors during electron FLASH delivery including surface guidance, checklists, and QA automation via failure mode and effects analysis (FMEA). Prior dosimeters utilized for UHDR beams were assessed for implementation considering dose linearity, dose rate independence, temporal resolution, and spatial resolution, including optical imaging methods viable for FLASH dosimetry. Imaging Cherenkov emission and radioluminescence demonstrated full field dose distribution at single-pulse (4 microsecond) and millimeter resolution. **In vivo** Cherenkov emission surface profiles were monitored with improved signal-to-noise ratio via an intensified camera. A diode EDGE detector characterized UHDR dose and dose rate at sub-millisecond resolution. A beam model of the modified LINAC was validated and implemented into a commercial clinical treatment planning software (TPS).

While this electron irradiation platform established ongoing investigations into the FLASH mechanism and large animal treatments in one institution, the identified dosimetry requirements, accessibility to conversion methods, and open-source beam model can catalyze studies in other clinics. Delivery and dosimetry can be further improved by identifying potential errors via an open access FMEA survey, resolving delivered temporal pulse structure, and ensuring pulse to pulse consistency.

Abstract 280 TUE-AP-MA-02-3 Invited Talk - Tuesday 2:30 PM - Quarter

Proton FLASH Accelerators: From high intensity beam to clinical relevance

Francois Vander Stappen

Research & Development, IBA - Ion Beam Applications, Louvain-La-Neuve, Belgium

FLASH radiotherapy is defined by a dose rate superior to a certain threshold, usually 40 Gy/s. This has shown beneficial effects by lowering toxicities on healthy tissues, compared to conventional dose rates. Protons are uniquely suited for FLASH as they combine the FLASH effect with the conformality of the Bragg peak and a long range for deep-seated tumors.

In this talk, we will first make an overview of the current and future technical solutions to deliver FLASH. We will point out the strengths and limitations of various types of beams and accelerators.

We will then discuss the dose rate definition. Whereas it is easy to define in the case of a continuous, broad, uniform, and single-field beam, it is less straightforward when we are facing multiple fields, intensity modulation, arc, or pencil beam scanning.

Finally, we will present achievements at UPenn's Roberts Proton Therapy Center equipped with IBA's ProteusPLUS system. A gantry room has been upgraded to deliver the proton beam with a FLASH dose rate, and pre-clinical trials have started on animals (mice, dogs). We will go through the developments brought to the system, from the cyclotron to the patient: beam current increase, beam energy modifying devices, beam quality monitoring and regulation.

Abstract 68 TUE-AP-MA-02-4 Contributed Talk - Tuesday 2:30 PM - Quarter

X-RAY FLASH RADIOTHERAPY SYSTEM BASED ON A HIGH POWER ELECTRON LINAC

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Emerging evidence indicates that the therapeutic window of radiotherapy can be significantly increased using ultra-high dose rate dose delivery (FLASH), by which the normal tissue damage is reduced without compromising tumor cell killing. The dose rate required for FLASH is 40 Gy/s or higher, 2-3 orders of magnitude greater than conventional radiotherapy. Among the major technical challenges in achieving the FLASH dose rate with X-rays is the linear accelerator that is capable of producing such a high dose rate. We will discuss the design of a high dose rate X-ray 18 MV linac with 100 Gy/s dose collimated into a tumor. While this linac builds on mature accelerator technologies that have been demonstrated already to produce high-power electron beams, such a high-power electron beam has never before been used to produce a high-quality therapeutic X-ray beam.

Abstract 105 TUE-AP-MA-02-5 Contributed Talk - Tuesday 2:30 PM - Quarter

Beam Delivery Tuning and Capability Estimation of Hitachi Synchrotron-based Particle Beam Treatment Systems for Ultra-high Dose Rate Radiotherapy

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Recently, ultra-high dose rate radiotherapy has been getting much attention as it can spare normal tissues while keeping tumor control. This effect (so-called FLASH effect) has been vigorously investigated using particle beams because an ultra-high dose rate beam is available in clinical treatment systems, most of which are cyclotron-based or synchrocyclotron-based. The treatment systems provided by Hitachi are composed of a synchrotron accelerator and can be suitable for ultra-high dose rate irradiation to various depths, but there have been only a few experimental studies reporting FLASH effects using a synchrotron-based system.

In this work, we tuned beam delivery designs for the Hitachi synchrotron-based proton therapy system at the Nagoya Proton Therapy Center and carbon-ion therapy system at the Osaka Heavy Ion Therapy Center to extract ultra-high dose rate particle beams. We also evaluated the dose, dose rate, and field size generated by the tuned beams.

In each system, beam extraction parameters were modulated to generate a shorter, flat, and higher-current beam pulse. The mean current of the tuned proton beam pulse was ~160 nA for a 50-ms length at a beam energy of 139 MeV. In the case of carbon-ion beams, the mean current was ≥20 nA for a 100-ms beam pulse at 208.3 MeV/u. From the above beam performance, the dose rate was estimated using various definitions when forming a 2 by 2 cm^2 irradiation field with a 2-cm spread-out Bragg peak. The averaged dose rate was higher than 40 Gy/s for both particles, even though this definition estimates a dose rate lower than other definitions.

These results indicate that Hitachi synchrotron-based particle beam therapy systems can perform ultra-high dose rate irradiation. Of course, beam-off times such as an energy-changing time should be considered for clinical use, but the tuned beams in this work are useful for FLASH experiments. In-vitro and in-vivo experiments are currently being conducted at several sites using the tuned treatment systems.

Abstract 69 TUE-AP-MA-02-6 Contributed Talk - Tuesday 2:30 PM - Quarter

Modeling the Beams and Transfer Lines of the McLaren Proton Therapy Center

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McLaren Proton Therapy Center functions as a clinically active, multi-room cancer treatment center. Beam size and current measurements are being utilized together with simulations to develop computer models for the Center's transfer lines and associated beam parameters. The primary computer tool utilizes a nonlinear, constrained optimization program that is integrated with a beam envelope code to find detailed beam phase space parameters (sigma matrices). Additional experiments use the quadrupole scan technique to independently determine beam parameters at selected locations. Beam current measurements along the beamlines are used to infer transmission efficiencies and compared to multi-particle

simulations in order to identify beam loss locations. The goal of the work is to develop an improved understanding of the beams and beam transfer lines to support further beamline optimization and design activities. An overview of the combined experimental and simulation methodology will be described, selected results presented, and potential future plans outlined.

Abstract 60 TUE-AP-TA-03-1 Invited Talk - Tuesday 2:30 PM - Pioneer III

Graduate Program at Texas A&M University Cyclotron Institute

Lauren McIntosh

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The Texas A&M University Cyclotron Institute has a vibrant graduate program which utilizes the K150 and K500 cyclotrons. Students from chemistry, physics, and engineering all utilize the facilities and equipment available as part of the DOE Center of Excellence. Experimental students get the opportunity to design hands-on experiments from start to finish, working closely with faculty and staff. Topics of fundamental interest in nuclear structure, reactions, astrophysics, fundamental symmetries, and superheavy elements are all studied at the TAMU Cyclotron Institute, in addition to more applied studies, such as isotope production for medical applications and chip testing with heavy-ion beams. Opportunities available to graduate students will be discussed.

Abstract 150 TUE-AP-TA-03-1 Invited Talk - Tuesday 2:30 PM - Pioneer III

Nuclear Science Education at the UMass Lowell Radiation Laboratory

Andrew M. Rogers

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The nuclear-physics program at UMass Lowell has a strong focus on both fundamental science and an established in-house infrastructure that is harnessed to support numerous advanced projects on detector development, instrumentation, and applied nuclear science. The UMass Lowell Radiation Laboratory houses a 5.5-MV CN Van de Graaff accelerator, a 1-MW research reactor, and a ~100-kCi ^{60}Co gamma irradiator located within the same building complex. Together, these facilities and laboratory resources provide a unique opportunity for our students, enabling them to develop experiences ranging from hands-on applied work to fundamental experimental and theoretical research at the forefront of nuclear science. Our Nuclear Instrumentation course, for instance, makes strong use of these resources and provides a solid foundation in instrumentation to a diverse set of students, including in medical physics and nuclear engineering. In this talk I will provide an overview of our program and discuss examples of research and educational activities, focusing on those that directly utilize our accelerator and reactor, and how they advance the education and training of students.

Abstract 157 TUE-AP-TA-03-2 Invited Talk - Tuesday 2:30 PM - Pioneer III

Graduate student teaching and research at the Nuclear Science Laboratory of Notre Dame

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University accelerator laboratories are in the unique position of being able to mentor and teach the next-generation of accelerator scientists, while collectively pushing the boundaries of current scientific understanding. The Nuclear Science Laboratory at the University of Notre Dame operates three local electrostatic accelerator systems and one located a mile underground in South Dakota. Ongoing research at these facilities is primarily focused on nuclear astrophysics, but also covers a wide range of fundamental and applied nuclear physics, and is only possible due to the strong participation of Graduate Student researchers. Some of the graduate research, training and opportunities made available through these facilities will be presented.

Abstract 235 TUE-AR-NST-03-1 Invited Talk - Tuesday 2:30 PM - Arabian

Ion implantation enabled solid-state platforms for quantum information processing

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Wide band-gap semiconductors host optically addressable spin qubit defects, such as the (NV-) center in diamond and the neutral divacancy (VV0) in silicon carbide (SiC), which serve as a versatile platform for a number of quantum information science (QIS) applications. Unfortunately, deterministic synthesis of defect-based qubit systems within wide-bandgap semiconductors remains a limiting challenge in bringing these systems from a fundamental science into a scalable quantum technological platform. Additionally, incorporating these defects into devices, presents unique challenges as growth and fabrication methods generally have deleterious effects on the qubit properties while also presenting undesired variability and unreliable yields. To this end, our recent research efforts have been concentrated on pushing our advanced x-ray based and optical characterization capabilities for nano-implanted defect creation processes. Our investigations focus on the defect creation process through a combination of growth, advanced fabrication, implantation, and annealing processes, while maintaining the spin, charge, and optical properties of the defects. Herein, we will present on how nano-scale ion implantation, in conjunction with synchrotron nano-diffraction is enabling our studies of deterministic defect creation in low dimensionality quantum materials for efficient qubit synthesis and hetero-integration.

Abstract 34 TUE-AR-NST-03-2 Contributed Talk - Tuesday 2:30 PM - Arabian

Detection of Single Low-Penetrating Ions in Diamond

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Diamond is one of the most promising materials for future quantum devices. Quantum centers in diamond, such as nitrogen vacancy, can serve as information carriers in quantum computers - qubits, but can also be used in quantum optics and quantum sensing. Development of such devices would require arrays of quantum centers to be created close to the diamond surface, with high enough yield. Deterministic single ion implantation as a technique for fabricating quantum devices relies on high precision in placing individual ions in the semiconductor material, together with the verification of the implantation of each ion by detecting the charge it induces in the semiconductor. This method has already been demonstrated for silicon substrate but has yet to be successfully performed for wide bandgap materials, such as diamond. This work focuses on understanding the critical parameters required for successful detection of shallow, low-energy ions in diamond using the best quality commercially available diamond crystal and state-of-the-art front-end electronics. Ion microprobe and IBIC (ion beam induced charge) technique were used to map the spatial distribution of CCE (charge collection efficiency) of the detector, a crucial parameter for single ion detection. To determine both the energy resolution of the detector, and to map the CCE distribution close to the surface, a series of irradiations was performed using ions of energy as low as 100 keV and penetration depth down to 100 nm. In order to achieve high energy resolution, necessary for detection of low-penetrating ions, XGLab CUBE charge preamplifier was used. The measurements were done both at room temperature and at low temperatures (down to -40°C). The successful detection of 140 keV copper ions that penetrate on average around 100nm was demonstrated and the best achieved energy resolution was 1.2 keV.

Abstract 99 TUE-AR-NST-03-3 Invited Talk - Tuesday 2:30 PM - Arabian

Focused ion beam applications using gas field and liquid metal alloy ion sources

Gregor Hlawacek

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Focused ion beams are often considered as tools required for the sample preparation for other techniques such as transmission electron microscopy. However, in this presentation I would like to convince you that by using other sources than ubiquitous Gallium liquid metal ion source a wide range of interesting and challenging problems can be addressed in a very flexible way. I will focus on applications enabled by the usage of gas field (GFIS) [1-3] and liquid metal alloy ion sources (LMAIS) [4].

Among other examples I want to present some recent results obtained using Ne and He GFIS based helium ion microscopy (HIM). I will show how the HIM can be used to create arbitrary shaped ferromagnets using $Fe_{60}Al_{40}$ [5] as well as anti-ferromagnets in Co/Pt/Ru multilayers(6)Using in-situ probing I will show how to tune the spin torque interaction in a Pt/Co/W multilayer sample such that current switchable magnetization patterns can be created (7)Finally, I'd like to present recent results related to the epitaxial overgrowth of tin spheres driven and observed by HIM [8].

In the second part of my talk I want to present results obtained using LMAIS based FIBs. This includes our recent effort to create single photon emitters (SPE) in Si. We use LMAIS based Si irradiation to create single W and G centers in two different Si base materials. The obtained yield for the G-centers is more than 50% and the lateral precision is ~100 nm. I will also show how this process can be scaled up to avoid the flexible but serial FIB approach and switch to broad beam irradiation (9)Finally, I want to show that also LMAIS based FIB can be used to control magnetic properties on the nanometer scale with high precision. Examples include the implantation of up to 10% of Co into permalloy with a lateral resolution of 30 nm and the control the Gilbert damping of the magnetization dynamics by four orders of magnitude using a Dy LMAIS. An outlook on new sources currently under development will conclude the talk.

Abstract 90 TUE-AR-NST-03-4 Contributed Talk - Tuesday 2:30 PM - Arabian

Simulation of ultra-low energy ion implantation of 2D materials

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Monte-Carlo based binary collision approximation (BCA) simulations provide a fast and versatile simulation tool for ion-solid interactions. We have developed the software IMINTDYN based on the SDTrimSP code to predict ion implantation, damage formation and ion erosion for ultra-low energy ion irradiation in the energy regime 20 eV to 500 eV and for complex single layer and multilayer 2D materials, like graphene and transition metal dichalcogenides. We will show that a proper choice of the collision cascade cutoff energy and the use of simultaneous weak collisions (not implemented in the SRIM code) is essential to achieve reliable simulations for irradiation with ultra-low energies. Moreover, we have implemented the vacancy as additional target species, which can be created and annihilated in the course of a collision cascade. The large spacing of 1 nm of graphene layers due to van-der Waals interaction can be simulated in a more realistic way by introducing vacancy filled layers between individual graphene layers. We present simulation results for ultra-low energy implantation of graphene single and multilayers as well as implantation into MoS_2 and $MoSe_2$ single and multilayer 2D materials using potential dopants such as B,N, Se, Mn, Fe-57 e.t.c.

Abstract 210 TUE-AR-NST-03-5 Invited Talk - Tuesday 2:30 PM - Arabian

Time-resolved magnetic microscopy of nanoparticles using nitrogen-vacancy centers in diamond

Bryan Richards[1,2], Nathaniel Ristoff[1,2], Janis Smits[1], Ilja Fescenko[1,3], Maxwell Aiello[1,2], Forrest Hubert[1,2], Yaser Silani[1,2], Nazanin Mosavian[1,2], Maziar Saleh Ziabari[1,2,4], Andris Berzins[1], Joshua Damron[1,5], Pauli Kehayias[6], Dale Huber[4], Andrew Mounce[4], Michael Lilly[4], Todor Karaulanov[7], Andrey Jarmola[8,9], Abdelghani Laraoui[1,10], Victor Marcel Acosta[1,2]

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Widefield magnetic microscopy using diamond with nitrogen-vacancy (NV) centers is an emerging technique in various fields, including the study of magnetic materials. A uniform layer of NV centers within 200 nm of the diamond surface, created by implanting nitrogen into electronic-grade diamond at a series of energies from 10 - 100 keV, enables the sensing and quantitative imaging of magnetic fields from samples. We report progress on the use of diamond magnetic microscopy to image the fields from single magnetic nanoparticles and study their relaxation dynamics.

Abstract 176 TUE-AR-RE-07-1 Invited Talk - Tuesday 2:30 PM - Pioneer IV

In-situ positron annihilation spectroscopy (iPAS)- A new tool for ion irradiation damage

Farida A Selim[1], Adric Jones[1], Matthew Chancy[2], Hyosim Kim[2], Thaihung Chung[1], Riley Ferguson[1], Samikshya Prasai[1], Peter Hosemann[3], Blas Uberuaga[2], Yongqiang Wang[2]

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In-situ measurements during irradiation are critical to monitor material response to irradiation in real time and several advanced in-situ techniques with remarkable capabilities have been developed to address that and examine material structure, properties, and performance under extreme irradiation environments. In-situ TEM has been particularly powerful in monitoring the microstructural changes and growth of cavities in real time during irradiation. However, revealing the mechanisms governing early formation of defects and their evolution in extreme environments require measuring defects on all length scale from atomic- to meso-scale. Positron annihilation spectroscopy is uniquely sensitive to atomic scale defects revealing their density, structure, size, and chemistry even in the very early stages of damage. In this talk I will describe the development of the first in-situ positron beam during high energy irradiation, discuss the challenges, advantages, and limitations. Early tests of the system will be presented to demonstrate the unique capabilities.

This work was funded as part of FUTURE (Fundamental Understanding of Transport Under Reactor Extremes), an Energy Frontier Research Center funded by the U.S. Department of Energy, Office of Science, Basic Energy Sciences.

Abstract 198 TUE-AR-RE-07-2 Invited Talk - Tuesday 2:30 PM - Pioneer IV

In-Situ Ion Irradiation and Compression of Micropillars inside a Transmission Electron Microscope

Ryan Schoell[1], Matthew DeJong[1], Phillip Alarcon[1], Ce Zhang[1], David Frazer[2], Peter Hosemann[2], Djamel Kaoumi[1]

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A study was conducted to investigate the response of ion irradiation on the mechanical properties of both 304SS and zirconium single crystals. Micropillars were fabricated using focus ion beam techniques and two crystallographic directions

were taken for the zirconium pillars. Ion irradiation was performed at Argonne National Laboratory's Intermediate Voltage Electron Microscope with krypton ions as well as Sandia National Laboratories Ion Beam Laboratory using gold ions. Some of the 304SS pillars were also subject to helium implantation before irradiation to study the effects of helium bubbles. Ion irradiations were conducted at temperature followed by compression using a PI-95 Pico indenter. The effect of crystal direction and ion irradiation damage was investigated in the Zr pillars while the effect of ion irradiation damage and helium implantation was investigated in the 304SS samples.

Abstract 207 TUE-AR-RE-07-3 Contributed Talk - Tuesday 2:30 PM - Pioneer IV

Radiation tolerance of Fe_3O_4 evidenced by reversible order-disorder phase transformation through in situ ion irradiation in a TEM

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Magnetite Fe_3O_4 is a common scale product that builts on Fe based alloys exposed to corrosion environment. Surprisingly, little is reported on the radiation behavior of this oxide in the literature. For this matter, pure foils of Fe were oxidized to form magnetite. Then thin foil lift-outs of the Fe/Fe_3O_4 heterostructures were irradiated in-situ in a TEM with 1 MeV Kr ions at various temperature. In this work we focus on the experimental results at 50K. The irradiation was performed in tow major steps. In the first step, the irradiation was done to 15 dpa and the sample was then allowed to naturally warm up to room temperature. In the second step, the sample was cooled once more to 50 K and irradiated to a final dose of 38 dpa. Firstly, evidence of the Verwey transition for some of the magnetite grains was recorded during the cooling processes although most of the oxide grains seems to retain the cubic structure. Under irradiation, the extinction of the first order reflections was observed in the diffraction patterns that were acquired at doses as low as 1 dpa. The stable reflections presented a d-spacing that correlated to the anion sublattice of Fe_3O_4 spinel. Moreover, upon naturally warming up the sample to room temperature, the reflections that vanished during irradiation reappeared, resulting in total recovery of the crystal. The disordering and displacement of the cations to unoccupied sites of the Fe_3O_4 crystal leading to a phase transformation are invoked to explain the results. The implication of cation lattice versus anion lattice disordering in the amorphization resistance of the spinel is also discussed.

Abstract 114 TUE-PR-SP-07-1 Invited Talk - Tuesday 2:30 PM - Palomino

Tomorrow's experimental capabilities, today: Proof-of-principle neutron capture experiments in inverse kinematics at LANSCE

Andrew Leland Cooper[1], Shea Morgan Mosby[1], Rene Reifarth[2], Aaron Joseph Couture[1], Dmitry Vladimirovich Gorelov[1], Ilija Draganic[1], Gordon Wendell Misch[1], Matthew Ryan Mumpower[1]

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[(2)]Goethe University, Frankfurt, Germany

The capability to directly measure neutron capture reactions on short-lived ($t_{1/2}$ ~ 1 min) radionuclides would grant access to all s-process and some i-process reactions in the laboratory, along with many reactions of interest to nuclear energy applications. However, a precision measurement is currently prohibited because the radiation field originating from the unstable stationary target overwhelms the detection system, the sample size of the target is too small, or the target lifetime is too short. A next-generation facility consisting of a high-intensity spallation neutron target coupled with a radioactive ion beam storage ring is being developed at the Los Alamos Neutron Science Center (LANSCE) to overcome these experimental challenges. In this new concept, the neutron source is driven by the 800-MeV proton beam from the LANSCE accelerator and outgoing neutrons are thermalized by a large-volume moderator surrounding the spallation target. Radioactive ion beams circulating within a storage ring intersecting the moderator encounter the standing field of neutrons and capture reactions take place in inverse kinematics. We present performance sensitivity study results from Monte Carlo N-Particle (MCNP) simulations of candidate neutron target facility designs and provide signal estimates for proof-of-principle experiments that could be fielded at LANSCE currently. The design, execution, and technical impact of these initial tests will be described.

Abstract 117 TUE-PR-SP-07-2 Invited Talk - Tuesday 2:30 PM - Palomino

Measurements of the ^{56}Fe(n,n'g) reaction at GENESIS

Joey Gordon[1], J. Batchelder[1], L. A. Bernstein[1,3], J. Bevins[4], D. L. Bleuel[2], C. Brand[1], J. A. Brown[1], A. Georgiadou[1], B. L. Goldblum[1,3], B. Frandsen[5], T. A. Laplace[1], T. Nagel[1]

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Improved inelastic neutron scattering and neutron-induced gamma-ray production data are needed for the next generation of nuclear technologies, from advanced reactors to space exploration, shielding applications, and detection platforms based on prompt neutron interrogation analysis. The Gamma Energy Neutron Energy Spectrometer for Inelastic Scattering (GENESIS), located at the 88-Inch Cyclotron at Lawrence Berkeley National Lab, is the first-ever array of neutron detectors coupled to high-purity germanium detectors designed to address these nuclear data needs. In addition to single particle measurements of quantities like double-differential gamma-ray production, GENESIS can more accurately measure secondary neutron energy-angle distributions by tagging on coincident, characteristic gamma-rays. Experiments with a 99.98%-enriched ^{56}Fe target were performed at GENESIS. These experiments used a broad-energy, collimated, time-resolved incident neutron spectrum from 14 MeV Thick-Target Deuteron Breakup (TTDB), measured in situ with a newly developed, kinematic-based neutron spectrometer. Some experimental challenges arising due to the time structure of the neutron beam motivated the development of a forward modeling approach for analysis and interpretation of GENESIS data. This presentation will describe the characteristics of the neutron beam and the array, the forward modeling approach, and preliminary results from the 56Fe experiments, including differential gamma ray production cross sections, and gamma-ray tagged scattered neutron energy-angle distributions.

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Abstract 84 TUE-PR-SP-07-3 Contributed Talk - Tuesday 2:30 PM - Palomino

Next Generation Fast Neutron Detector With High Position Resolution

Thomas Baumann[1], Adriana Banu[2], James A. Brown[3], Paul DeYoung[4], Nathan Frank[5], Paul Gueye[1,6], Anthony Kuchera[7], Belen Monteagudo Godoy[4], Thomas Redpath[8], Warren F. Rogers[9]

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The investigation of neutron-unbound states using rare isotope beams in the energy range of 100 to 200 MeV/u by means of invariant mass analysis of the decay products requires the accurate measurement of the emitted fast neutrons. Such

approach has been the research topic of the MoNA Collaboration for many years using the large-area neutron time-of-flight detector arrays MoNA and LISA. MoNA-LISA, as well as other current neutron detectors that are used in similar measurements, offers high neutron detection efficiency but limited position resolution. These detectors are based on long plastic scintillator bars with photo-multiplier tubes attached on each end. While the position along the bar can be derived from the time difference of the signals from each end, the perpendicular position is defined by the size of the bar and location within the array. The MoNA Collaboration is planning to construct a plastic scintillator array for fast neutron detection that uses a different light readout based on a silicon photomultiplier (SiPM) array, which will enable much higher position resolution. In this presentation the new concept of light readout will be introduced and the current state of detector development will be discussed.

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Abstract 251 WED-PS-AR-01-1 Plenary Talk - Wednesday 8:45 AM - Kincaid

Recent pump-probe advancements to interrogate materials dynamics at ultra-fast temporal and atomic spatial resolutions

Mianzhen Mo

SLAC National Accelerator Laboratory, Menlo Park California, United States

In this talk, we will review recent progress in characterizing the ultrafast excitation and materials dynamics using the technique of Ultrafast Electron Diffraction (UED) at MeV energies. The application of MeV high-brightness electrons, generated by a photocathode radio-frequency gun, has significantly enhanced the performance of UED in following dynamics at atomic-scale spatial and temporal resolutions. With MeV-UED, we have conducted a number of different experiments resolving material dynamics on time scales as short as 100 fs with Ångstrom spatial resolution. Initially motivated by the need to understand the material responses to harsh environments produced by fusion plasmas, we successfully visualized heterogeneous and homogeneous melting transition in gold under extreme conditions [1], and captured the incipient plasticity in dynamically compressed aluminum (2)Importantly, our time-resolved diffraction data quantified the dependencies on nucleation seeds in ultrafast melting, and have determined dislocation nucleation and transport that constitute the underlying defect kinetics of incipient plasticity. Comparisons with modeling that include two-temperature Molecular Dynamics simulations reveal the crucial role of the choice of the inter-atomic potentials to describe the material state in extreme conditions. The successes of these studies have motivated us to expand this research area at SLAC; the combination of structural data from UED and the ion irradiation capability at LANL is now providing new insight into questions ranging from melting behavior [3] to transport properties of materials subject to radiation damage from extreme fusion environments.

[1] M. Mo et al. Science 360, 1451 (2018).

[2] M. Mo et al. Nature Comm. 13, 1055 (2022).

[3] M. Mo et al. Science Advances 5, eaaw0392 (2019).

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Abstract 264 WED-AA-IBTM-02-1

Invited Talk - Wednesday 10:00 AM - Kincaid (Hybrid)

The use of AGLAE to identify the origin and production processes of French stained glass windows

Claudine LOISEL, Barbara Trichereau

Stained-glass department, Laboratoire de recherche des monuments historiques, Champs-sur-Marne, France

Since 2006, a long-term research project by the **Laboratoire de recherche des monuments historiques** (LRMH) and the **Centre de Recherche et de Restauration des Musées de France** (C2RMF) has concentrated on the use of the AGLAÉ particle accelerator (**Accélérateur Grand Louvre d'Analyses Élémentaires**) to analyse French stained glass. AGLAÉ has high analytical performances and is non-invasive and non-destructive, as no sample is taken from the objects and the materials analysed are not modified in any way. In the case of stained glass windows, the panels can be placed directly in front of the beam. When stained glass windows are under restoration, this provides a unique opportunity for researchers to study the chemical compositions of both glass and paints and thus extend current knowledge of French stained glass. Several projects benefitted from a session at AGLAÉ from the 13th to the 19th centuries. PIXE, PIGE and RBS spectroscopy were used to carry out non-invasive and non-destructive analyses on the panels to identify the quantitative chemical composition of the different pieces of glass.

A most relevant example is the study of the glass from Auch Cathedral (south of France, Occitanie). The windows were created between 1510 and 1513 and signed by the glass-painter Arnaud de Moles. The results revealed a very homogeneous composition for all the glass samples except for those with a purple colour. Analyses were carried out on both sides of the glass and revealed the use of flashing for the red, green and blue glass samples. The glass composition was then compared with those of other sites in France, and a similarity was found with the composition of the stained glass made in the first years of the 16th century for Saint-Etienne's Cathedral in Sens. Archives from the Sens site note that the glass was purchased from a glasshouse in the Lorraine region. We can therefore assume that the glass sheets used by Arnaud de Moles came from the same supplier, located a thousand kilometres from Auch. The exceptional quality of the glass and the remarkable preservation of the windows have enabled us to extend existing knowledge on the manufacturing processes of coloured glass and the 16th century trade networks used for their commerce.

AGLAÉ is therefore well-fitted for inorganic compounds and precious works of art such as stained glass.

Abstract 151 WED-AA-IBTM-02-2

Contributed Talk - Wednesday 10:00 AM - Kincaid (Hybrid)

Ion Beam Analysis of Ancient North and West African Metals and Glass

Stewart Bragg Younger-Mertz[1,2], Quentin Lemasson[3], Thomas Fenn[2], Claire Pacheco

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[(3)]AGLAE, C2RMF, Palais du Louvre, Paris, France

To better understand contacts between North and West Africa from the late 1st millennium BC to the first millennium AD, two collections of archaeological materials (copper-based metals and glass), one from North Africa and one from West Africa, were selected for ion beam analysis. One collection of materials originated from the site of Meninx, situated on the coast of the island of Djerba, Tunisia, while the second originates from Walaldé, a large habitation mound located in the Middle Senegal River Valley in Senegal. Both sites have materials dating from as early as 500BC to about 500AD, an important period associated with the advent of trans-Saharan trade. These analyses can provide important information on production recipes for trade materials, and these in turn can be used to potentially connect production and/or source areas for the raw materials/finished goods and the locations where these materials are consumed after long distance trade and exchange.

Abstract 142 WED-AA-IBTM-02-3

Contributed Talk - Wednesday 10:00 AM - Kincaid (Hybrid)

Converting New AGLAE IBA data into digital heritage objects

Claire Pacheco[1,2,3], Enora Bulting[3], Maxime Cattet[3], Kevin Straszburger[3], Witold Wroblewski[3], Quentin Lemasson[1,2], Laurent Pichon[1,2], Léa Ferfaille[2], Marine Zelverte[2]

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On April 15th 2019, Notre-Dame de Paris was burning. The glass-stained windows have fortunately been preserved but were polluted by lead. These colorful iconic objects are deposited now and some of them will be studied in 2022-23 at the New AGLAE facility. Once restored, the precious artifacts will go back to the cathedral for centuries, hardly accessible for further physic-chemical analysis.

Integrating and sharing scientific data within the frameworks, norms and processes of **Open Science** should be considered as the alpha and the omega of any study of Cultural Heritage entity. As a matter of fact, if the property of a Cultural Heritage object is not always institutional, its cultural and spiritual dimension is intrinsically universal and belongs to anyone. According to the UNESCO **World Heritage Convention** dating from 1972 and now signed by 194 states, it is **the duty [of France] of ensuring the identification, protection, conservation, presentation and transmission to future generations of the cultural heritage.**

So, how should we consider the IBA data acquired on such specific targets? Are they part of the cultural heritage object which will then be digitally augmented? Are they part of a **digital twin** of the piece of art?

Hence, the mission of the New AGLAE team is to preserve and transfer the IBA data sets acquired on precious objects made of stones, glass, ceramics, metals, etc. and dating from Paleolithic to 21st c. to future generations as a piece of digital cultural heritage, starting by making the data respect the FAIR principles (Findable, Accessible, Interoperable, Reusable). The FAIR process is optimized along the IBA data life cycle, from the application for New AGLAE beam time to the perennial storage of data sets and the publication of data, through their processing and current storage.

Following this logic and also in order to improve the various uses of IBA data within the communities built around the New AGLAE, IBA for Cultural Heritage and more widely Heritage Science, the **Euphrosyne** project was conceived. Euphrosyne is not only Aglae's sister in mythology, but it is also the name of the digital platform that is being developed with the **Digital Workshop** of the French Ministry of Culture to make the New AGLAE data FAIR.

Euphrosyne first version was deployed in March 2022 and enables New AGLAE users first to prepare their experimental run which is an essential step for high quality measurements and the FAIRification of the future dataset. The digital tool also permits to safely reach their data. The team is now working on the next version of **Euphrosyne,** which should present more functions such as giving remote access to some New AGLAE processing software. Finally, the digital tool should enable interrogating, accessing and sharing IBA data respecting the FAIR principles.

The issues, methodology and challenges will be presented as well as the progress status of the **Euphrosyne** platform.

Abstract 48 WED-AA-NBAT-01-1

Invited Talk - Wednesday 10:00 AM - Pioneer III

Exploring quantum and correlated materials with neutron scattering

Alessandro R Mazza

Los Alamos National Laboratory, Los Almaos NM, United States

Neutron scattering provides a unique vantage on both composition and behavior of materials, having the ability to resolve to meV excitations, orientation and arrangement of magnetic moments, and sensitivity to nuclear density and isotopic substitution. These character traits make them an ideal probe to novel properties emerging in correlated and quantum materials - from topotactic phase transitions to quantifying disorder in magnetic topological insulators. In this talk, we focus on two recent revelations resulting from in-situ neutron reflectometry studies. First, in the intrinsic magnetic topological insulator $MnBi_2Te_4$, it is shown that the formation of a surface oxide layer is drives large changes in the anomalous Hall effect - explaining the inconsistent emergence of the quantum anomalous hall effect in various studies. Second, in a prototypical correlated material, $La_{0.7}Sr_{0.3}MnO_3$, the effect of deoxygenation/hydrogenation is explored. Changes in oxygenation and hydrogenation produce electronic structure changes that manifest broadly as metal-insulator transitions, emergence of superconductivity, or magnetic ordering. However, poor understanding of the fundamental mechanisms of hydrogenation and a lack of systematic studies makes the understanding of these electronic and magnetic properties difficult to digest. In this arena, we report on a new mechanism for oxygen vacancy formation and ordering by hydrogenation. The most significant result of this work is that in contrast to previous reports, the **in-situ** NR measurements reveal that the phase transformation of LSMO is driven by a transient mechanism limited to the film surface without protons ever entering the lattice. These results demonstrate the strength of **in-situ** studies in understanding phase transformations and emergent properties in oxide systems.

Abstract 147 WED-AA-NBAT-01-2

Invited Talk - Wednesday 10:00 AM - Pioneer III

Neutron Study of Dynamics of Fluids of energy applications

Naresh C Osti

Neutron Scattering Division, Oak Ridge National Laboratory, Oak Ridge Tennessee, United States

Electric double-layer capacitors, called supercapacitors, are attracting much attention for energy storage applications. Behaviors of confined fluids at the interface between electrodes and electrolytes are critical to control the performance of supercapacitors. Here, we demonstrate the capability of the neutron as a probe to explore the structure and dynamics of various types of electrolytes in bulk and confined states in different electrode materials using a suite of neutron scattering techniques. Microscopic dynamics of those fluids as observed by quasi-elastic neutrons scattering (QENS) will be presented.

Abstract 101 WED-AA-NBAT-01-3

Invited Talk - Wednesday 10:00 AM - Pioneer III

Electrode-electrolyte interfaces of ionic liquids probed by neutron reflectometry

Jeffrey M Klein

MPA-11, Los Alamos National Laboratory, Los Alamos New Mexico, United States

Ionic liquids (ILs) are an emerging class of electrolyte with improved thermal and electrochemical stability compared to conventional electrolytes. A unique aspect of ILs is the complete absence of solvent molecules which causes local liquid ordering that is amplified by the presence of an electric field. As a result of local ordering, the standard Gouy-Chapman-Stern model used to describe the conventional electrical double layer is inadequate for describing the IL interface. Contrary to the standard double layer model, molecular simulations and experimental procedures have suggested that a multilayered structure is formed at the IL-electrode interface. Quantifying the number of individual layers, as well as the density and composition of each is an important step in developing new "double-layer" models which can describe the IL-electrode interface.

Neutron reflectometry (NR) provides a unique opportunity to probe the density, composition, and thickness of the multilayered structure near electrode surfaces. Chemically modified silicon surfaces offer a strategy to maintain the smooth surfaces needed for NR data resolution while providing the means to mimic an electrode charge based on the termination group electron density. Here a series of modified silicon surfaces with roughness <6 Å are used to probe various solid-liquid interfaces formed with the IL $[N_{1888}]$(TFSI)Since the number density and composition of each layer may differ from the bulk liquid, a vast number of possible scattering length densities (SLD) may be observed. SLD models can be constrained to a calculated range of SLD values to reduce the possibility of non-physical fits and identify the predominant ion present in a given layer. Reflectivity profiles on gold, native silicon, hydrogen terminated silicon, and quartz demonstrate both disordered and single layered liquid structures. Preliminary profiles of the fixed-potential $[N_{1888}]$[TFSI] | Au interface have been measured, and results suggest only minor differences in interface structure as a result of applied potential.

Abstract 62 WED-AP-MA-01-1 Invited Talk - Wednesday 10:00 AM - Quarter

Novel Accelerators for Linac-Based Radiotherapy

Sergey V Kutsaev[1], Salime Boucher[1], Brahim Mustapha[2], Ke Sheng[3]

[(1)]RadiaBeam, Santa Monica CA, United States
[(2)]Argonne National Laboratory, Lemont IL, United States
[(3)]Department of Radiation Oncology, University of California, Los Angeles, Los Angeles CA, United States

The three most popular radiation oncology technologies are based on using beams of photons, electrons, and hadrons (protons and heavy ions). Photon radiotherapy is currently a quite mature and advanced technology and continues to evolve toward improvement of its medical effectiveness, and set the requirements toward the radiation source, which is typically an electron linear accelerator (linac). For example, novel techniques that involve tumor irradiation from 4π angle or FLASH ultrafast delivery of large doses cannot be efficiently realized with the existing accelerators. At the same time, hadron radiotherapy promises improved treatment outcomes in certain cases. Efforts are underway to develop more compact hadron linac technologies with the ability to change the beam energy in millisecond time scales for efficient spot scanning. In this talk we will overview the current trends in linac technologies for electron, photon and hadron therapy, and provide examples of such developments at RadiaBeam.

Abstract 213 WED-AP-MA-01-2 Invited Talk - Wednesday 10:00 AM - Quarter

Upright Particle Beam Therapy

Niek Schreuder, Rock Mackie, Stephen Towe

Leo Cancer Care, Middleton WISCONSIN, United States

Treating and imaging patients in the upright orientation is gaining acceptance in radiation oncology and radiology and has distinct clinical advantages over the recumbent position. Other benefits of treating patients in the upright position include the reduction in the size of the treatment room and the reduced shielding requirements. Both these aspects are helping to enable installing proton therapy beam delivery and position systems in existing LINAC bunkers. We will discuss the size and shielding requirements for upright systems and show how existing radiation therapy infrastructure at existing clinics can be repurposed for particle therapy.

Abstract 140 WED-AP-MA-01-3 Contributed Talk - Wednesday 10:00 AM - Quarter

Development of Variable-Energy Accelerator with Fixed Field for Particle Beam Therapy

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There is a growing interest in particle therapy worldwide, but further popularization requires a reduction in system area and an increase in throughput. We are developing a fixed-field variable energy accelerator to reduce the accelerator size and improve the dose rate of particle therapy systems. Although this accelerator is a fixed-field accelerator, it is characterized by its ability to extract proton beams of various energies from a single extraction channel by configuring an eccentric beam trajectory.

In this accelerator, a frequency-modulated radio frequency (RF) field is applied to the circulating beam in a main magnetic field to accelerate the beam. During acceleration, the beam is oscillating around equilibrium orbit stably, by focusing force provided by weak-focusing field. The main magnetic field is a decreasing with respect to the outer radial direction of the orbit, and it is formed by combination main superconducting coil with magnetic poles. Horizontal tune is kept in the region of greater than 0.96 and less than 1. When the beam reaches near the irradiation energy, the accelerating RF is stopped at a predetermined time. After the RF field is stopped, the beam in a stable orbit is diffused by the transverse RF field in the RF kicker. The beam is then guided into the extraction channel by peeler and regenerator magnetic field. These, the peeler and regenerator, are magnetic fields added at the outside of the beam orbit with opposite gradients to each other and have the function of bringing the horizontal tune closer to 1 while keeping the vertical stability of the passing beam. This effect excites a second-order resonance of the beam oscillation for particles displaced outside the equilibrium orbit, which exponentially increases the displacement from the equilibrium orbit. The beam then reaches the entrance to the extraction channel, which is located further out from the peeler and regenerator. And the beam is extracted through the magnetic channel composed of ferromagnetic materials. At the entrance of the extraction channel, the lower the energy, the more outward the direction of motion of the beam. Conversely, at the exit, the magnetic field is excited so that the higher energy beam passes through the outside.

It is characterized in that all beam paths up to the collector magnet are formed by a static magnetic field. Therefore, this method enables fast energy control without a degrader in the transport system, and is expected to obtain high irradiation current, in the all over energy region. Furthermore, beam irradiation can be controlled by transverse RF, and controllability of the irradiation dose can be ensured. As result, high dose rates that reduce patient treatment time will be achieved.

The hardware configuration for stable beam acceleration and extraction is derived from electromagnetic field analysis and particle tracking analysis in three-dimensional space, and the energy-variable beam extraction from the accelerator is demonstrated by simulation. These simulations were performed in considering with a geometry and structure of main magnet and other component that is ensuring the fabrication feasibility of the accelerator. Therefore, we conclude that the feasibility of this idea for the energy-variable accelerator is assured.

In this presentation, we mainly describe the system configuration of the accelerator, the results of the particle tracking analysis, and the evaluation of the dose rate.

Abstract 265 WED-AP-MA-01-4 Invited Talk - Wednesday 10:00 AM - Quarter

Design and Comparative Performance of a Proton Therapy Linac

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The first linac for proton therapy (LIGHT) system has been fabricated, installed, and accelerating 230 MeV protons. It is modular, compact, low loss, and is expected to provide superior performance. The 3 GHz LIGHT system includes a 750 Mhz Radio-Frequency Quadrupole (RFQ), Side-Coupled Drift Tube LINAC (SCDTL) cavities, Cell Coupled Linac (CCL)

cavities, High Energy Beam Transport (HEBT), and a patient treatment room including modulated, pulse by pulse scanning, and patient positioning.

The LIGHT system is currently being tested and installed at locations in Cheshire, and London, UK. The status of the installations and testing will be discussed as well as further developments of LIGHT technology and its clinical application including for FLASH.

Abstract 70 WED-AP-SD-03-1 Invited Talk - Wednesday 10:00 AM - Pioneer IV

Ultrawide Bandgap Ga_2O_3 Sensor Materials for Harsh Environment Applications

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As an emerging ultrawide bandgap compound material, Ga_2O_3 has shown excellent potential for a series of sensing applications in harsh environment. In this presentation, we report our progress in developing Ga_2O_3 materials for radiation detection. We investigated the X-ray detection performance of high resistivity β-Ga_2O_3, which exhibited high linearity between the X-ray induced current and the X-ray tube current. The as-fabricated detector prototypes showed high signal-to-noise ratio exceeding 10^3 at low applied voltage (-5 V) together with excellent stability. Both the rise and the fall times of the X-ray induced current displayed no experimental lag (measurement time steps = 0.3 seconds), indicating two orders of magnitude faster response in Fe-doped β-Ga_2O_3 compared to that in undoped β-Ga_2O_3. We further investigated possible charge transport mechanisms based on the transient and stable X-ray induced current response shape and time evolution. Our study shows that Fe doping of β-Ga_2O_3 significantly improves the transient performance of β-Ga_2O_3-based X-ray detectors, preserves their high signal-to-noise ratio and linearity, and enables the ambient-temperature operation and zero-power operational mode capability. Detailed material characterization and detector analysis will be offered in this presentation.

Abstract 146 WED-AP-SD-03-2 Invited Talk - Wednesday 10:00 AM - Pioneer IV

Scintillators for Accelerator Science,

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Discovery of novel scintillators addresses national security needs to improve detection of special nuclear materials. Two classes of materials are under investigation for high energy X-ray radiography applications: Cerium doped high entropy rare earth aluminum garnet ceramics and europium doped inorganic metal halide perovskite single crystals. Both have demonstrated promising scintillation properties, namely low afterglow of the garnet ceramics and high light yield (70,000 ph/MeV) of the perovskites.

Crystal growth and characterization of newly discovered rubidium halide perovskite compounds will be discussed. Scintillation properties, including light yield, afterglow, decay time, and energy resolution were investigated. Ongoing studies include investigations on the intrinsic radioactive background from the naturally occurring Rb-87 radioisotope, crystal scalability (22 mm diameter), and radiation hardness of select compounds.

This material is based upon work supported by the U.S. Department of Homeland Security under Grant Award Numbers 20CWDARI00036-01-00 and 20CWDARI00037-01-00. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Department of Homeland Security.

Qualifying $LaBr_3$ Detector Performance for the Mu2e Experiment at Fermilab Using the ELBE Accelerator

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Background: The Mu2e experiment at Fermilab will search for Charged Lepton Flavor Violation (CLFV) processes by monitoring $10^{17\text{-}18}$, at rest, μ-lepton decays. The muons are produced using an 8-GeV kinetic energy proton beam from the Fermilab accelerator complex on a production target. First, producing π-mesons which decay to μ-leptons, which are then transported to a stopping target where CLFV decays can be observed. The experiment is normalized by estimating the number of stopped μ-leptons. The number is directly proportional to the 1808.7 keV γ-ray emitted promptly in the muon nuclear capture process in the aluminum target measured using a $LaBr_3$ detector. The stopping target generates an energy flux of 3.2×10^8 TeV/s, consisting of muons, electrons, neutrons, X-rays, γ-rays and other particles in the presence of which the shielded $LaBr_3$ detector is required to accomplish its counting task.

Purpose: For the experiment's normalization, the number of μ-stops will be monitored by use of a large, 3 inch right cylindrical $LaBr_3$ detector to measure γ-ray lines at 1808.7 keV, 844 keV and 347 keV, related to the number of stops. The 1.7 μsec Mu2e beam cycle starts with a 200 ns wide beam "flash" followed by a 1.2 μsec quiet data collection period. The average γ-ray energy is ~5 MeV but ranges as high as ~65 MeV. In addition, the beam has a cycle, 340 ms on, followed by 1 s off, with short bursts of high intensity periods on the time scale of 5-10 ms. These beam fluctuations are expected to be as high as 5 to 6 times nominal intensity. The high energy flux can overwhelm the detector's electronics rate capability and also cause radiation damage to the detector. In order to model the detector's expected performance at Mu2e test beam experiments were conducted at ELBE electron accelerator at the Helmholtz-Zentrum, Dresden-Rossendorf, Germany, using its 15 MeV pulsed bremsstrahlung beam.

Method: To mimic the Mu2e environment the ELBE accelerator was operated at 406 kHz, 812 kHz and 1.6 MHz pulse rates, set to have characteristics of the Mu2e beam "flash" energy and time structure. In addition a 200 kBq mixed radioactive calibration source was used to produce surrogate Mu2e γ-ray lines, including 4 kBq of ^{88}Y producing an 1836 keV line. The $LaBr_3$ crystal's transducer consisted of an 8 dynode PMT and a simple, 4 power supply electronic base design. From the collected data sets the detector's gain, and energy resolution as a function of average energy flux was measured to rates as high as 1~Mcps. The detector sustained energy fluxes up to 1 TeV/sec for 0.34 sec and 4 TeV/sec for 5 msec, matching Mu2e experimental requirements.

Results: At the Mu2e nominal counting rate of 140 kcps, the PMT gain decreases 3.5% as a result of the PMT inter-dynode insulator charging effect. The short bursts of high intensity periods result in minor change in overall gain. Both these effects are modeled and corrected for, resulting in an energy resolution of 17 keV at 1808.7 keV, or an increase in nominal energy resolution of 5 keV compared to the best achievable resolution of the detector.

Conclusion: The $LaBr_3$ detector is capable of measuring the Mu2e normalization at a nominal counting rate of 140 kcps with 5 MeV average energy, and with fluctuations up to 700 kcps, without significant loss of energy resolution.

Lens-coupled MeV X-Radiography with Transparent Ceramic GLO Scintillators

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Lens-coupled X-ray computed tomography (X-ray CT) using a transparent scintillator imaged on a CCD camera obtains higher spatial resolution than the more commonly employed phosphor-enhanced amorphous silicon (A-Si) panels. A-Si panels are limited to resolution typically greater than ~200 microns, have a limited working life due to degradation with dose, and provide intrinsically low efficiency with thin (few hundred microns thick) phosphor coatings. Demanding applications such as imaging the interior of complex additively manufactured components require high throughput and high resolution, best achieved with a lens-coupled system. However, for large fields-of-view, very large area but thin transparent scintillators are required - a format difficult to fabricate with high light yield single crystals - therefore, glass scintillators with both modest X-ray interaction and light yield have been used for years. We have developed a new polycrystalline transparent ceramic scintillator, $Gd_{0.3}Lu_{1.6}Eu_{0.1}O_3$, or "GLO," that offers excellent stopping power and light yield for improved contrast in sizes up to 14" x 14" plates, with thicknesses in the 2-10 mm range, and we are implementing it in systems to increase imaging throughput for 9 MeV Bremsstrahlung X-ray CT. CT imaging performance will be described.

Abstract 137 WED-AP-SD-03-5 Contributed Talk - Wednesday 10:00 AM - Pioneer IV

A Compact Inexpensive Charged Particle Detector for Studying Nuclear Physics

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A complete charged particle detection system has been fabricated using all surface mount components to minimize size and cost. The charge sensitive detection element is made from a modified PN junction photodiode (Vishay BPW21R) with an active area of 5mm x 5mm. A 3-stage precision amplifier is employed in the detection electronics to convert the small (sub-picoamp) charge generated by the detection element into a shaped pulse with a FWHM value of ~20-40us and peak intensity of ~250mV/MeV. The pulsed output signals are then coupled to the integrated analog-to-digital converter (ADC) of a 32-bit microcontroller (Microchip SAMD21) and processed for pulse height analysis. Overall, the entire hardware stack is approximately the size of a AAA battery and utilize UART for data transfer while drawing power from the +5V rail of the USB. Preliminary results show that the PN junction is sensitive to alpha particles of energy 5.41MeV emitted from radioactive isotope Po-210 as well as energetic protons of energy 3.02 MeV from the D-D fusion reaction. The noise floor for the detector was improved to approximately 10mVRMS by using battery power. This represents a signal-to-noise ratio (SNR) of approximately 135 for Po-210 alpha and 76 for D-D proton signals. We believe that the detector system can be a useful tool for studying various fundamental nuclear physics reactions that are important for a variety of applications including security and defense.

Abstract 139 WED-AP-SD-03-6 Contributed Talk - Wednesday 10:00 AM - Pioneer IV

YAP:Ce Crystals as Beam Monitor for CRYRING@ESR

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CRYRING@ESR is in operation since 2021, with allocated beam time for proposed experiments in high-precision atomic physics, already before the start of the FAIR project. It stands out as the only facility world-wide providing beams of stable and radioactive ions and rare isotopes dressed with few electrons or totally stripped in the energy range below 14 MeV/u down to rest. [1,2]

The main requirements for the components used at CRYRING are given by the ultra-high vacuum (up to 10^{-12} mbar), high temperature resistance, mechanical strength and fair tolerance for radiation. YAP:Ce scintillators qualify for this purpose representing a robust, yet cost effective solution when coupled to a photomultiplier positioned externally. [3,4]

The ion irradiation effects on the YAP:Ce efficiency has been studied by irradiating pristine single crystal YAP:Ce at 300 K to various ion fluences with gold ion beams in the range of a few keV/u. The preliminary results reveals an exponential decrease of the YAP:Ce efficiency, with steep damage after the first 4 irradiation steps which corresponded to a fluence of $4x10^{12}$ ions/cm^2; however, with further increase in ion fluence (i.e., up to $1.5x10^{13}$ ions/cm^2) the photon yield continued to diminish, but at a slower rate. Surprisingly, 24 h after the last exposure, YAP:Ce crystals recovered to 70% of the initial yield due to a self-annealing effect that may reduce the stress levels in the irradiated region. Further ex-situ X-ray diffraction analysis will be necessary to enable new mechanistic insight into the atomic nature of the observed recovery in YAP:Ce.

Acknowledgements

This work was performed within the **YAP:Ce Heavy Ions Detector for CRYRING** (ROCRYDET) project that is funded by the Romanian Ministry of Research Innovation and Digitization under the FAIR-RO programme administered by the Institute of Atomic Physics, Romania. Experiments were carried out at 3 MV Tandetron™ accelerator from "Horia Hulubei" National Institute for Physics and Nuclear Engineering (IFIN-HH) and were supported by the Romanian Government Programme through the National Programme for Infrastructure of National Interest (IOSIN) [5].

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A quantitative method to determine the region not influenced by injected interstitial and surface effects in ion-irradiated metals

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Accelerator-based ion irradiation has been widely used in nuclear engineering to emulate neutron irradiation, especially when considering the phenomenon of void swelling. However, ion-neutron equivalence is complicated by many issues. One major issue is the injected interstitial effect in which the implanted extra atoms act as interstitials and suppress void swelling. This effect is real, but how to define the region affected/unaffected by this reactor atypical effect has been a topic of great debate. The study concerns the credibility of accelerator irradiation in nuclear materials testing and also the reliability of the data extracted. We propose and demonstrate a microstructurally-based experimental method to quantitively determine the depth regions in self-ion-irradiated metals that are affected by the injected interstitial effect and various surface effects, focusing on the choice of safe analysis zones to minimize the impact of these phenomena. The goal is to define the depth ranges where extracted data can be confidently applied to ion-neutron correlations for reactor application. Since ion energies in the range of 1 to 5 MeV are most frequently employed by the radiation effects community, we conducted irradiations at four energies in this range. The experiment was conducted on relatively pure single crystal iron. It was shown that ion energies of ≤1 MeV did not yield a safe depth range, but irradiations at 2.5 MeV and above yielded useful safe zones with predicted swelling behavior becoming independent of ion energy. The surface-affected zone width was roughly twice that of the void-denuded zone width. The interstitial-affected region starts at about one-half of the projected range and does not show any "spreading" of influence in depth when the peak damage level increases from 50 to 100 displacements per atom (dpa). This study provides confidence that enhances the credibility of ion simulation when applied to void swelling in neutron environments.

Abstract 107 WED-AR-RE-08-2 Invited Talk - Wednesday 10:00 AM - Arabian

Creation and characterization of diamond color centers by means of ion beam implantation

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Diamond has been widely explored in the last years as a possible hosting platform for single photon sources due to the availability of several classes of optically active defects (usually referred to as "color centers") that can be suitably engineered in its crystal structure. To date, the most prominent type of defect is the so-called negatively-charged nitrogen-vacancy center (NV), due to several key features of this system, namely: photo-stability at room temperature, high quantum efficiency and most importantly unique spin properties with great potential for applications in quantum sensing and computing. The need for single-photon emitters displaying desirable opto-physical properties (high emission rate, narrow linewidth) has also motivated the discovery and characterization of several classes of optical centers in diamond alternative to the NV complex, based (among others) on group-IV elements impurities (Si, Ge, Sn, Pb [1]), noble gases (He [2], Xe [3]) etc. In this context, ion implantation represents a powerful and versatile tool to engineer a broad range of different types of color centers, allowing for the fine control of key parameters such as ion species and energy, as well as irradiation fluence to determine the type and density of defect complexes. Up to now though, the number of the emitters characterized by a reproducible fabrication process is fairly limited, and a systematic investigation in this field is still to be finalized. Thus, the fabrication of novel luminescent defects with desirable properties upon the implantation of selected ion species still represents a crucial strategy to achieve further advances in the field. In the present contribution a systematic study on several novel color centers in diamond will be reported, namely on the fabrication of Sn-[4], Pb-[5], F-[6] and Mg-related color centers. The fabrication process consisted of ion beam implantation at different energies followed by subsequent thermal annealing. The formation of stable luminescent defects has been assessed by means of a single photon sensitive photoluminescence confocal microscopy setup. Further, the characterization of the color centers has been performed at both ensemble and single-photon levels, in a temperature range of 4-300 K using several different excitation wavelengths. This work represents a relevant progress in the study of diamond color centers, both in the attribution of an articulated series of spectral features and in the understanding of the formation process of these types of defects, thus clarifying the potential of these systems for high-impact applications in quantum technologies.

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Abstract 78 WED-AR-RE-08-3 Contributed Talk - Wednesday 10:00 AM - Arabian

On the Use of SRAM Based Dosimeters to Measure LET and Fluence in Heavy Ion Facilities

Ryan Dean Rinderknecht, Lawrence Ethan Henderson

Texas A&M University Cyclotron Institute, College Station TX, United States

In this talk, we discuss the development of an SRAM based dosimeter for verification of the heavy ion beams at the Texas A&M Cyclotron Institute. The device has been extensively tested over a plethora of beams, and it shows promising results.

The dosimeter consists of 4 Cypress 90 nm SRAMs, chosen for their resistance to latch up. Data have been collected on 10 different species of 15 MeV/u ions using both the K500 and K150 cyclotrons at Texas A&M. The total bit cross section is a strong function of LET. The SRAMs have a threshold LET near the Bragg peak of alpha particles, and never showed any signs of saturation, with the total bit cross section staying fairly linear all the way from 15 MeV/u Nitrogen to 15 MeV/u Gold. Both accelerators make use of five scintillators mounted inside the beamline to measure fluence and, when used in conjunction with the SRAM dosimeter, can be used to measure beam purity. The process of setup and beam verification takes only a few minutes.

The talk will heavily focus on the statistics of our measurements, including an in-depth discussion of the interplay between our existing scintillator setup and the SRAM dosimeter. Additionally, the effects of and measurements of multiple bit upsets will be elucidated. Special emphasis will be made showing the computed cross section variance, which is a nontrivial function of the scintillator setup, beam fluence and shape, and multiplicity distribution of the SRAMs.

Abstract 13 WED-AR-RE-08-4 Contributed Talk - Wednesday 10:00 AM - Arabian

Electronic Excitation Induced Effects on the Structural and Electrical Properties of HfO2 thin films

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The Si-based Complementary Metal Oxide Semiconductor (CMOS) devices have been the workhorse of microelectronics where successive down scaling of the technology nodes has been the preferred route for improvement of device performance. The excellent material properties of Si and SiO_2 combined with the reliability of SiO_2/Si interface have played an important role for more than four decades of progress. The fundamental limit occurs from the aggressively scaled

down ultrathin SiO_2 layer, where leakage in several current components due to quantum tunneling becomes excessively high. To overcome this degradation in performance, researchers are considering advanced gate stacked MOS structures based on high-k oxides and III−V compound semiconductors. Among the many promising candidates HfO_2/GaAs based devices have electrical properties that are acceptable for use in MOS device applications. Electronic excitation effects on the performance of these devices is current interest.

In this work, the effects of electronic excitation induced by Swift Heavy Ion (SHI) irradiation on the structural and electrical properties of HfO_2 thin films deposited on GaAs substrates have been studied. A systematic growth of HfO_2 grains and introduction of crystalline phases such as monoclinic and tetragonal phases in otherwise amorphous HfO_2 thin films have been observed after irradiation. The Photoluminescence (PL) spectra revealed the variation in defect configuration related to O-vacancies and slight shift in the peak positions after irradiation, which indicate the generation of strain within the film which is responsible for the SHI induced evolution of crystalline phases in HfO_2 thin films. Further, Au/HfO_2/GaAs based MOS structures have been fabricated to study the effects of electronic excitation induced by SHI irradiation on the electrical properties of these devices. The influence of Poole-Frenkel (PF) and Fowler-Nordheim (FN) tunneling processes have been investigated by examining the Leakage Current-Voltage (I-V) characteristics. The tunneling mechanisms showed the existence of defects in the as-grown HfO_2 film. Ion induced defect annealing has been observed at lower fluences which leads to decrease in the leakage current density, whereas ion induced defect creation has been observed at higher fluences which caused a systematic increase in the leakage current density. This study offers worthwhile information for understanding the effects of electronic excitation on the electrical properties of HfO_2/GaAs based photonic and optoelectronic devices, when such devices are operated in a radiation harsh environment.

Abstract 204 WED-PR-SP-08-1 Invited Talk - Wednesday 10:00 AM - Palomino

Neutron beta-decay studies at LANL

Maninder Singh

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Beta decay of a free neutron is the simplest form of "semi-leptonic" weak interaction and is free from nuclear structure effects. Despite the simplicity of the process, it's lifetime measurement remains one of the most challenging measurements, bearing different results depending on the technique ("bottle" or "beam") (1, 2)Another critical measurement from the decay is the correlation (A_o) between the neutron's initial spin and emitted electron's momentum. Neutron lifetime and axial neutron charge determined using A_o are inputs to determine the magnitude of the Cabibbo-Kobayashi-Maskawa (CKM) matrix element (V_{ud}) and provide a means to study physics beyond the Standard Model.

Los Alamos National Laboratory hosts two experiments (UCNτ and UCNA) to measure the lifetime and beta-asymmetry parameters, exploiting the ultra-cold neutron (UCN) beam. UCNs at LANL are produced via the downscattering of moderated spallation neutrons in a solid deuterium crystal and are polarized via transport through magnets (3)The UCNτ experiment is undergoing upgradation in terms of the design to achieve more storage of UCNs to gain higher sensitivity limits and better precision. This contribution will discuss details of the UCNτ experiment and expected new results.

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Abstract 100 WED-PR-SP-08-2 Invited Talk - Wednesday 10:00 AM - Palomino

Active target measurement of the ^{35}Cl(n, p) and ^{35}Cl(n, α) cross sections utilizing a CLYC detector at The Edwards Accelerator Lab

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The ^{35}Cl(n, p) and ^{35}Cl(n, α) reactions are important inputs to designs of molten chloride fast reactors, a class of molten salt reactor utilizing chloride salts. There is presently a lack measurements in the range of 0.1 - 0.6 MeV. We have measured these cross sections from 0.1 - 3.0 MeV utilizing a ^{6}Li-enhanced (> 95%) CLYC detector as an active target; approximately 45% of the detector active target atoms are ^{35}Cl. The measurements were made with the 4.5 MV Tandem Pelletron, Beam Swinger, and Time-of-Flight Tunnel facilities at Edwards Accelerator Lab at Ohio University utilizing a ^{9}Be(d, n) white-spectrum neutron source. The detector was placed at 5 m from the neutron source and the time-of-flight technique was used to measure neutron energies. A Geant4 simulation of the Time-of-Flight Tunnel and detector has been constructed. We present the measurements in the 0.1 - 0.6 MeV and compare to previous measurements in overlapping energy ranges. A brief overview of the neutron science capabilities and other ongoing projects at The Edwards Accelerator Lab will be presented.

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Abstract 120 WED-PR-SP-08-3 Contributed Talk - Wednesday 10:00 AM - Palomino

Measuring Alpha Induced Alpha Knockout Reactions Using the NIMROD 4π Detector Array at Texas A&M University

Zachary Tobin[1,2], Kris Hagel[2], Alan McIntosh[2], Roy Wada[2], Austin Abbott[1,2], Jerome Gauthier[2], Travis Hankins[1,2], Andrew Hannaman[1,2], Bryan Harvey[2,3], Ashley Hood[2], Yiu-Wing Lui[2], Laura McCann[1,2], Lauren McIntosh[2], Robert Rider[1,2], Steven Schultz[1,2], Maxwell Sorensen[1,2], Kamila Zelga[2], Sherry Yennello[1,2]

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Alpha conjugate nuclei are light, N=Z nuclei with a structure that can be described as consisting of ^{4}He subunits. Beyond certain threshold energies, these nuclei have been observed to decay into multiple alpha particles (such as the case of the Hoyle state in ^{12}C). For low-lying states, these nuclei are mostly described by a mean-field structure coexisting with some degree of pre-formed cluster structure. Knockout reactions were used to investigate the degree of clusterization present at low-lying states in alpha conjugate nuclei. A beam of 60 MeV/u ^{4}He was impinged on targets of different alpha conjugate nuclei (^{12}C, ^{16}O, ^{24}Mg, and ^{28}Si). The Neutron Ion Multi-detector for Reaction Oriented Dynamics (NIMROD), a near 4π detector array, was used to examine alpha induced alpha knockout reactions. This coverage is necessary to efficiently detect pairs produced in the knockout reactions. NIMROD detector response/characterization and preliminary results will be discussed.

Abstract 56 WED-PR-SP-08-4

Contributed Talk - Wednesday 10:00 AM - Palomino

Simulations of the Multi-layer Active target for MoNA Experiments (MAME) with Garfield++

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The study of neutron unbound systems via the invariant mass technique is the primary focus of the MoNA Collaboration, which built and operates the MOdular Neutron Array (MoNA) and the Large multi-Institutional Scintillator Array (LISA). Reaction cross-sections for producing neutron unbound systems from radioactive ion beams can be small, 0.1-1mb, and the use of a thick reaction target degrades the resolution of the measurement. As an upgrade to a pre-existing Si-Be segmented target, the Gas Electron Multiplier (GEM) technology is being investigated for its use in a Multi-layer Active target for MoNA Experiments (MAME) for the Collaboration's research program at the Facility for Rare Isotope Beams with a possible expansion to missing mass capability. A GEM-based detector could allow for a higher degree of Be-foil segmentation. Performance studies are conducted using Garfield++ to understand electron transport within MAME including GEM configurations, electron position distribution, drift speed, signal generation, and simulation optimization. A Geant4 simulation is being developed to work in tandem with the Garfield++ simulation to model the detector response along with the physics of the reaction/decay process. Preliminary results from simulation studies will be discussed.

Abstract 247 WED-AA-IBTM-04-1

Contributed Talk - Wednesday 12:30 PM - Arabian I/II/III

Development and Testing of a System for Light Element Particle Induced X-Ray Emission

Todd A Byers, Charles T Bowen, Bibhudutta Rout, Gary A Glass

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The improvements made to ultra-thin windows for silicon-drift detectors in recent years has allowed for the detection of elements as light as lithium. However, their use with particle induced X-ray emission (PIXE) typically requires the addition of an absorber thick enough to prevent backscattered light ions from reaching the detector. This also blocks lower energy X-rays, preventing them from reaching the detector. A prototype system has been developed to allow for the detection and measurement of X-rays from light elements, which can be particularly useful for applications in many fields. An overview of the system and testing methodology will be presented. Light element PIXE was performed on a variety of samples with a 500 x 500 μm^2 1 MeV proton beam, with elements of $5 \leq Z \leq 30$ being successfully detected. The resultant PIXE spectra for two biological samples were quantified using GeoPIXE. This system is currently under development for micro-PIXE application.

Abstract 121 WED-AA-IBTM-04-2

Contributed Talk - Wednesday 12:30 PM - Arabian I/II/III

ToF-ERDA - New detectors, New spectrometer

Mikko Laitinen

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Elastic recoil detection analysis (ERDA) was first time used in 1976 for determining the depth distribution of light elements in heavy materials (1)The light element analysis was, and is, challenging for the Rutherford backscattering spectrometry as

RBS excels in "heavy materials on light substrate". The ToF-ERD technique in which both the time-of-flight (ToF) and energy (E) events are measured in coincidence, was introduced in 1983 (2)Contrary to the RBS, ToF-ERD excels in "light materials on heavy substrate". Today, ToF-ERDA has enabled quantitative elemental depth profiling of all sample elements in the sample, including hydrogen but also the heaviest elements.

The time-of-flight measurements are nowadays realized by detector design developed in the 80's (3)Similarly, gas ionization detectors, were invented more than 80 years ago. However, despite the original principles being old, the state-of-the-art ToF-ERD detectors used today are a result of the continuous long-term scientific research [4].

As a one outcome of the scientific work, there has also been a push, from outside institutes, for commercial deliveries of such ToF-ERDA spectrometers. The most recent Jyväskylä delivery was a complete ToF-ERD spectrometer / end-station to the beam line at the University of Surrey 2022. The talk goes through the key characteristics of modern TOF-ERDA tool: a) timing and energy detectors, b) background/noise suppression and detection efficiency (of light elements) c) sample damage and depth resolution, and d) analysis of the data. These are combined with the short introduction of the aspects of the commercialization of the scientific equipment sales to other institutes.

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Abstract 77 WED-AA-IBTM-04-3 Contributed Talk - Wednesday 12:30 PM - Arabian I/II/III

Methods for External Proton Induced Gamma and X-ray Emission (PIGE and PIXE)

Gunnar McAndrews Brown, William Kacey, Graham Peaslee

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Proton-Induced Gamma and X-ray Emission (PIGE and PIXE) are standard Ion Beam Analysis (IBA) techniques to precisely measure isotopic and elemental abundances in a wide range of sample types. While performing these analyses in vacuum has been standard procedure and offers excellent sensitivities, it also limits the number and size of samples that can be run. To increase sample throughput, the St. Andre facility at Notre Dame has been conducting PIGE and PIXE experiments **ex vacuo** to expand the application of these IBA techniques as rapid scanning techniques. Large sample throughput and rapid analysis increases viability of these techniques for health and environmental applications. Due to increased sample throughput and variety, new sample preparation techniques and external standard methods have been developed. These techniques are being applied to quantify **ex vacuo** measurements of particulate matter (PM) aerosol pollution, indoor dust samples, and road dust samples. Preliminary data collected in Indiana will be discussed.

Abstract 122 WED-AA-IBTM-04-4 Contributed Talk - Wednesday 12:30 PM - Arabian I/II/III

Elastic scattering and recoiling cross-sections measured by ToF-ERDA for low energy heavy ions

M. Kivekäs[1], K. Mizohata[2], M. Kainlauri[3], M. Prunnila[3], L. Keränen[4], M. Putkonen[4], M. Laitinen[1]

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Time-of-Flight Elastic Recoil Detection Analysis (ToF-ERDA) is a powerful technique used for quantitative elemental depth profiling of thin film samples (1)Using low energy heavy ion beam for ToF-ERDA has at least 3 benefits: increased film to substrate signal, less beam induced damage due to higher cross-sections and increased film depth resolution (2)Use of low energy, heavy ion beams also introduce some drawbacks, one of which include heavily screened cross-sections for low energy heavy ions - or at least the obvious discrepancy between detected and calculation-based events in the detector. This discrepancy is now being investigated with experimental methods and the measurements using JYFL ToF-ERDA setup (1,3)Co, Au, Y2O3 and La2O3 thin film compositions were characterized beforehand using 2 MeV RBS setup to where ToF-ERDA results are compared against to.

Our results demonstrate a clear discrepancy for detected cross-sections relative to the Rutherford (and Anderssen correction) cross-sections calculated from scattering and recoiling yields (Fig. 1). Detected relative cross- sections of scattering beam stay rather constant through the measured beam energy range, while relative cross-sections of recoiling target show strong incident ion beam energy dependency. Reason of this discrepancy is not yet well known, some of it might be due to more pronounced scattering of heavier ions in ToF telescope or errors in tabulated cross-sections for low energy heavy ion collisions. More detailed results together with the hypothesis of the origin of this discrepancy will be presented.

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Abstract 236 WED-AA-IBTM-04-5 Contributed Talk - Wednesday 12:30 PM - Arabian I/II/III

Minimum detectable levels of biologically relevant elements in thin film samples using PIXE

Charles Thomas Bowen, Cory Nook, Gary Glass

Phyiscs, University of North Texas, Denton Texas, United States

PIXE analysis was conducted on FIsherbrand™ qualitative p8 grade filterpaper samples soaked in elemental standard solutions to determine the minimum detectable levels of Al, Si, P, S, Cl, K, Ca, Cr, Fe, Ni, Cu, and Se. All samples were analyzed with beam parameters of 2μc incident charge, and beam current of less than 2nA. Minimum detectable levels were obtained by analyzing the x-ray spectrum in the GeoPIXE analysis package, and the data for each element would be averaged over all collected spectra. The minimum detectable level in parts per million was found to be on average 9.59 for Al, 4.6 for Si, 3.23 for P, 2.27 for S, 1.82 for Cl, 1.15 for K, 0.88 for Ca, 0.51 for Cr, .07 for Mn, 0.54 for Fe, 1.59 for Ni, 2.0 for Zn, 1.55 for Cu, and 6.5 for Se. Minimal deviation from the averaged values was observed, except in cases where samples contained high concentrations of elements with overlapping x-ray energies.

Abstract 229 WED-AA-IBTM-04- Contributed Talk - Wednesday 12:30 PM - Arabian I/II/III

Ion Beam Analysis of Elemental Constituents in Rat Organs - Male/Female Comparisons

Cory S. Nook[1], Subash Sapkota[2], Bibhudutta Rout[1], Karen P. Briski[2], Gary A. Glass[1]

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[(2)]School of Basic Pharmaceutical and Toxicological Sciences, College of Pharmacy, University of Lousiana at Monroe, Monroe LA, United States

Past research on bio-inorganic element distribution and concentrations in the body, performed at the whole-organ level, has provided a valuable platform for investigation of the role of these micronutrients in physiological and behavioral functions. Heretofore, emphasis on potential sex differences in elemental concentrations in the presence versus absence of physiological stimulation has been non-existent. However, elucidation of any correlations between effects of specific treatments and the relationship to the functional heterogeneity of cell types that comprise individual organs necessarily requires discriminative mapping of relevant elements according to the cytological organization of those organs. This study utilized particle induced x-ray emission (PIXE) spectrometry and Rutherford backscattering spectrometry (RBS) to investigate effects of hypoglycemia, a recurring complication of diabetes disease management, on elemental composition of function-specific areas of primary organs (liver, kidney, brain) in male and female rats (Rattus Novegicus). Detectable sex-specific baseline and/or treatment associated levels of Fe, K, Cu, Ni, Se, and other higher Z elements that correlate with organ microscopic anatomy are expected to illuminate sex-dimorphic reactivity to physiological and pathophysiological challenges.

* Supported in part by NIH Grant DK 109382

Abstract 24 WED-AA-NBAT-02-1

Invited Talk - Wednesday 12:30 PM - Pioneer III

Technology for portable fast neutron generators

Clark Snow

Neutron Generator Applied Science and Technology Maturation, Sandia National Labs, Albuquerque NM, United States

Neutron generators come in a wide range of sizes, from immense building sized facilities to portable handheld units. In this presentation I will focus on those neutron generators that generally are less than 1 cubic meter in size and produce fast neutrons from the D-D (2.45 MeV) and D-T (14.4 MeV) fusion reactions. The three main technologies utilized for portable fast neutron generators are the dense plasma focus (DPF), inertial confinement fusion (ICF), and linear accelerators. I'll give an overview of each of these technologies with their strengths and weaknesses. The most common portable fast neutron generator to its simplicity and flexibility is the linear accelerator. Each linear accelerator has three main components, an ion source, an ion acceleration region, and a target. I'll describe each of these three regions in detail. The purpose of this presentation is to familiarize the audience with the workings of portable fast neutron generators so that they can make reasonable judgments on which device will be most suitable for their particular applications.

This paper describes objective technical results and analysis. Any subjective views or opinions that might be expressed in the paper do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

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Abstract 175 WED-AA-NBAT-02-2

Contributed Talk - Wednesday 12:30 PM - Pioneer III

Integration by simulation of carbon nanotube electron field emitter on a Penning ion source

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Carbon nanotubes (CNTs) have many advantages over conventional semiconductor and metal emitters for electronic emission through the field emission. In this sense, we developed by simulation a novel field ionization neutron generator using CNTs as electron emitter.

CNTs via electron addition provides to decrease the ion plasma time creation equivalent to neutrons time appearance governing the generator performances. The generator composite by: a Penning ion source with CNTs, a ion extractor field and a target. The performance of this source was investigated by CST Studio Suite by focusing on electron life time. Firstly, we design the penning ion creating a 3D model and generating a simulation source. Secondly, we adjusted parameters to increase the electron path by modifying: electric field applied to the CNTs, magnetic field and electric field present in the ion source. This research work demonstrates the interest of CNTs source addition by doubling ionization particles creation.

Abstract 73 WED-AA-NBAT-02-3 — Contributed Talk - Wednesday 12:30 PM - Pioneer III

Validation of a Digital Data Acquisition System for Pulsed Neutron (n,n')and (n,n'γ) Measurements at the University of Kentucky Accelerator Laboratory

Yongchi_Xiao[1], Sally F. Hicks[1,2], Erin E. Peters[1], Steven W. Yates[1], Sarah E. Evans[2], Elizabeth A. Chouinard[2], Benjamin P. Crider[3], Jeffrey R. Vanhoy[4], Daniel S. Araya[3], Stephan_Vajdic[3], Avi_Perkoff[4]

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The University of Kentucky Accelerator Laboratory (UKAL) features a 7-MV CN Van de Graaff, which generates pulsed monoenergetic neutrons for use in basic and applied research. Measurements are made of elastic and inelastic neutron scattering with both neutron and γ-ray detection in the time-of-flight mode. A new digital data acquisition system has been implemented to enable an enhanced set of analysis techniques. The system, which is built upon the 15-bit CAEN V1782 (100 MSPS) and 14-bit CAEN V1730SD (500 MSPS) modules, must manage the 1.875 MHz beam pickoff timing pulse in addition to signals from fast scintillators, germanium detectors, a BGO anti-Compton shield, monitor detectors, and several scalars. Signals from various detectors as well as the beam pick-off signals that occur every 533 ns are digitized and recorded with time stamps, controlled by CAEN CoMPASS software. In addition, the capture of waveform is now available for better pulse shape discrimination and digital filtering. The details of the implementation and validation of this system in (n,n'γ) and (n,n) measurements and the enhancement of analysis techniques will be described. Research at UKAL is supported in part by the U.S. National Science Foundation under Grant No. PHY-2209178 and the U.S. Department of Energy under Contract Nos. DE-SC00056, DE-SC00424, DE-SC0021243 and DE-SC0021175.

Abstract 257 WED-AA-NBAT-02-4 — Contributed Talk - Wednesday 12:30 PM - Pioneer III

Development of a neutron-based method for the on-site fuel inspection

Davorin_Sudac[1], Jasmina_Obhodas[1], Vladivoj_Valkovic[1], Karlo_Nad[1], Zeljko_Orlic[1], Milorad Korolija[1], Mario_Kolar[2], Miroslav_Lucic[2], Jadranka_Cubric[2], Kristina_Jedvaj[2]

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Up to 20% of ethanol, base oil, or gas condensates are sometimes illegally added with the purpose to produce a cheaper fuel at the expense of its quality. Fuels, compared to the additives mentioned above, are more expensive because of applied excise and customs duties. The normal customs procedures include random fuel sampling by opening tanks of trucks at the border crossings to check the compliance of their cargo with the customs declarations. Although some fast-onsite tests exist, very often more precise laboratory analyses of fuel samples are needed, which may take several days to receive the results. We have investigated the possibility of using a neutron-based system to determine the elemental composition and density of gasoline, diesel, and different fuel mixtures such are gasoline/ethanol, diesel/base oil, and diesel/gas condensate. It was shown that by using associate particle imaging method (API), it is possible to analyze the elemental composition and density of different types of fuels and various kinds of fuel mixtures on-site, without opening fuel tanks and slowing down the border traffic. These analyses can be done in addition to the already well-developed API method for the on-site cargo inspection of illegal materials such as drugs and explosives.

Acknowledgment

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Abstract 9 WED-AA-NBAT-02-5 Contributed Talk - Wednesday 12:30 PM - Pioneer III

Determination of heavy elements in water and sediment along the Savannah river using Instrumental Neutron Activation Analysis

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[(2)]*Nuclear Reactor Program, Department of Nuclear Engineering, North Carolina State University, Raleigh North Carolina, United States*

Water and sediments along the Savannah river, which flows through the industrial, commercial and nuclear areas of South Carolina and Georgia, were investigated for heavy elemental pollution levels due to anthropogenic activities. Human Activities such as industrial and agricultural processes and atmospheric inputs have resulted in an increased flux of heavy elements in land and water, which introduce adverse effect on human health and aquatic life. Analysis of thirty samples from different locations from South Carolina to Savannah showed the presence of Cr, Mg, Mn, Al, Sc, Se, Rb, Zr, Zn, V,etc. The concentrations of Al, Ba, Zn, Cr, Mg, V in the waters ranges between 0.04-1.99, 0.08-2.8, 0.017-0.9, 0.005-1.5, 0.4-5.5, 0.0001-0.007 mg/l, respectively. The sediments samples collected near Jackson and Martin at South Carolina showed higher concentration of Cr, Zr, Rb,Co, V and Al elements whereas samples from Savannah region showed higher concentration of Se Cs, Fe, Zn, Mn and Mg elements

Abstract 255 WED-AP-MA-04-1 Invited Talk - Wednesday 12:30 PM - Appaloosa (Hybrid)

New paradigms in particle therapy - DECT and Particle radiography

Niek Schreuder[1], Rock Mackie[1], Stephen Towe[1], Mark Pankuch[2], Fritz De Jongh[3]

[(1)]*Medical Physics, Leo cancer care, Madison Wisconsin, United States*
[(2)]*Medical Physics, Northwestern Medical, Warrenville Illinois, United States*
[(3)]*Medical Physics, Proton VDA, Warrenville Illinois, United States*

The benefits of particle beam imaging are well understood since the early days of particle beam therapy. The use of proton radiography has been demonstrated in the 70's at the Harvard cyclotron laboratory and again in 1996 when the first proton radiography (P-Rad) images on animals were obtained at the Paul Scherrer Institute in Switzerland. Despite of all the documented benefits P-Rad has not been implemented clinically at any particle therapy facility.

The main reason for the lack of widespread implementation of these important technologies is that it's very difficult and expensive to install these technologies in rotating gantries. Installing these technologies in fixed beam rooms is much easier. However, since the fixed beam rooms at the majority of proton therapy facilities are mainly used for prostate treatments, the need to install these technologies in existing fixed beam rooms was limited. Furthermore P-Rad requires very high energy proton beams to obtain lateral P-Rad images in the pelvic region.

Introducing upright treatments now changes this paradigm. Upright treatments using technologies such as the upright patient positioner and upright dual energy CT (DECT) scanner being developed by Leo Cancer Care will allow for treating the majority of disease sites in fixed beam rooms. This in turn justifies the installation and clinical implementation of particle beam imaging technologies.

We will show how P-Rad imaging systems will be installed and implemented in the clinical workflow of future upright particle therapy treatment rooms equipped with the Leo upright patient positioners and upright DECT scanners.

Abstract 277 WED-AP-MA-04-2 Invited Talk - Wednesday 12:30 PM - Appaloosa (Hybrid)

In vivo imaging in the particle therapy

Xuanfeng Ding

Radiation Oncology , CoreWell Health William Beaumont University Hospital, Royal Oak Michigan, United States

The talk will overview the major challenges in the proton beam therapy clinical practice such as range uncertainties and address the immediate need for in vivo dosimetry. I will touch base on the exsiting technology including point dose measurement, 2D measurement and 3D measurement devices and their clinical applications.

Abstract 17 WED-AP-MA-04-3 Contributed Talk - Wednesday 12:30 PM - Appaloosa (Hybrid)

Assessment of a Radiological Imaging System Proof-of-Concept for Carbon Radiotherapy Real-Time Monitoring

Anissa Bey[1], Chris Beltran[2], Jiasen Ma[1], Jedediah Johnson[1]

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Carbon ions unite high physical and radiobiological selectivity stemming from their narrow Bragg peak and clustered DNA damage properties, respectively; making carbon radiotherapy a promising modality to treat certain difficult cancer cases.

Particle therapy treatment planning requires, however, accurate knowledge of the ion range in traversed tissues to ensure precise dose delivery and confinement to the targeted tumor volume. This range information is conventionally derived from empirical conversions of Hounsfield Units maps, obtained in X-ray CT scans, to ion relative stopping powers, and constitutes one of the leading uncertainties in ion-driven radiotherapy planning (1)Similarly, organ motion and patient anatomical changes during the course of treatment pose inherent challenges for accurate spatial dose delivery. Hence, an

ongoing goal in the radiotherapy field is to obtain real-time, patient individualized actionable imaging information during dose delivery to enable corrective or adaptive treatment options [2].

This research aimed to develop a radiological imaging solution to meet these clinical needs. The project assessed the byproduct, beam-like radiations generated in hadronic interactions of few GeV-accelerated carbon ions with tissues to identify persistent monitoring signatures and devise an instrumentation system to image dose delivery. The proposed imaging system accommodates a number of constraints: no charged particle identification requirement, no prior information about the incoming carbon beam, as well as currently available detector and read-out electronics technologies. Feasibility assessment Monte Carlo simulations were completed, implementing the geometry of a prospective clinical carbon therapy delivery nozzle, a water phantom, the monitoring system's proof-of-concept - which utilizes pixelated detectors operated in coincidence, and event-by-event data acquisition.

In this contribution, technical details of the proposed hadronic imaging system will be presented, along with key findings on the extracted clinically relevant features that could facilitate instantaneous carbon therapy verification upon further developments.

[1] M.F. Moyers et al., Report of the AAPM Particle Beams Task Group No. 202, American Association of Physicists in Medicine (2020).

[2] J. Bertholet et al., Phys. Med. Biol. 64, 15 15TR01 (2019)

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Abstract 126 WED-AP-MA-04-4 Contributed Talk - Wednesday 12:30 PM - Appaloosa (Hybrid)

Cooling Flow Analysis of Accelerator Based Molybdenum-99 Production from Molybdenum-100 targets.

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Accelerator Operations and Technology - Mechanical Design Engineering, Los Alamos National Laboratory, Los Alamos New Mexico, United States

Production of metastable Technetium-99 (Tc-99m) is vital to the medical imaging community. It is a radioactive tracer that emits gamma rays as it decays and it is these gamma rays that are then detected through imaging. Tc-99m is extracted from the decay of Molybdenum-99 (Mo-99) which has a half-life of about 2-3 days. One method of generating Mo-99 is using accelerator based technology, through the irradiation of Mo-100 using an electron beam. This is part of the NNSA's mission to produce Mo-99 commercially, within the US, without the use of highly enriched uranium (HEU) in support of nonproliferation and global security. Los Alamos National Laboratory (LANL) is working with NorthStar medical Radioisotopes (NMR) on their efforts to produce Mo-99 from the irradiation of Mo-100 targets. The NMR target consists of an Inconel window that allows the electron beam to penetrate and irradiate a stack of Mo-100 discs. The irradiation process generates large amounts of heat and requires extensive cooling of the targets using pressurized helium gas. Before beam on target, the design of the target stack and target housing is tested at LANL using a variety of experiments and accompanying computational fluid dynamics and heat transfer simulations. In the experiments, induction heating is used to simulate volumetric heating on the window, or on a single disc and is accompanied by calorimetry, displacement and temperature measurements. High speed imaging and laser based diagnostics experiments are used to investigate flow induced vibrations and to quantify the velocity field of the helium gas around the target housing to estimate whether the cooling provided is sufficient for the design. Computational models of the full target provide a complete picture of the effect of beam heating and helium flow through the target and the viability of the current design. Results from the experiments and modeling efforts are presented.

Abstract 212 WED-AP-MA-04-5 Invited Talk - Wednesday 12:30 PM - Appaloosa (Hybrid)

A journey to SPArc and future roadmap towards clinical implementation

Xuanfeng Ding

Proton therapy center, Beaumont Health, Royal Oak Michigan, United States

Rotating hundreds of tons of proton gantry while delivering the spot and energy layers with a submillimeter accuracy sounds like science fiction. This talk will review the journey of SPArc technology from a concept to a prototype through the research and development partnership with our industry partner IBA.

Learning points:

1. the history of the proton arc therapy development;

2. Recent technique breakthrough which enables the rotation proton arc therapy in a clinical

proton system at Beaumont;

3. Potential clinical benefits and applications;

4. Treatment planning optimization algorithm;

5. Preliminary data from quality assurance measurements

6. Future roadmap toward the clinical implementation of such treatment technology.

Abstract 196 WED-AR-RE-03-1 Invited Talk - Wednesday 12:30 PM - Pioneer IV

Radiation Effects and Thermal Stability in Ferritic Steels and High Entropy Alloys

Eda Aydogan[1], Osman El-Atwani[2], Bayram Berk Tanrisevdi[1], Ozgun Umut Tukac[1], Ali Ozalp[1], Hyosim Kim[2], Yongqiang Wang[2], Stuart A. Maloy[3], Yunus Eren Kalay[1]

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[(3)]Pacific Northwest National Laboratory, Richland Washington, United States

There is a worldwide need of nuclear energy due to the increase in the world's population and the desire to reduce greenhouse gasses from burning of fossil fuels. However, nuclear energy systems operate under high temperatures and stresses, chemically corrosive environments, and high neutron fluxes. Engineered ferritic alloys are one of the best materials for high temperature and extreme radiation environments. Moreover, a new class of materials, refractory high entropy alloys (RHEAs), has demonstrated great promise. In this study, thermal stability and radiation resistance of a

nanostructured ferritic alloy (NFA), 14YWT, produced by powder metallurgy methods, and TiZrHfNbTa and CrMoTaTiV RHEAs produced by vacuum arc melting and additive manufacturing techniques have been investigated. Recently, we have shown that NFAs and RHEAs are extremely stable up to >1000 ºC and they show almost zero swelling and radiation hardening under high dose heavy ion irradiation at various temperature ranges.

Abstract 192 WED-AR-RE-03-2 Contributed Talk - Wednesday 12:30 PM - Pioneer IV

An in silico method for the determination of crystalline defect relaxation volumes - bcc Fe as a test-case

Mohamed El-Bakouri El-Haddaji[1], Jean-Paul Crocombette[2], Alexandre Boulle[4], Alain Chartier[3], Aurelien Debelle[1]

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[(2)]SRMP, Universite Paris-Saclay, CEA/DES, Gif-sur-Yvette, France
[(3)]SCCME, Universite Paris-Saclay, CEA/DES, Gif-sur-Yvette, France
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Crystalline defects, inevitably produced upon ion irradiation, generate long-range elastic distortions of the lattice that are subtle driving forces for the defects to migrate and cluster. It is usually at this stage of defect clustering that the changes in the material properties are the most pronounced. Modelling defect creation and subsequent evolution is a multi-scale approach that requires basic data characterics of those defects. Elastic properties such as the relaxation volumes (Ω^{rel}) are highly useful, as they can be the principal ingredients in estimating the strains and stresses on a macroscopic scale (at least to some extent), they are required in phase-field modeling of radiation effects in materials, and they can also help exploiting X-ray diffraction experimental data related to irradiation-induced changes in the lattice parameters.

In this work, Ω^{rel} of common crystalline defects in bcc iron (Fe), chosen as a test-case material, was determined from molecular dynamics (MD) simulation cells containing defects of varying size and concentration. We used both real and reciprocal space data: the former allowed to monitor the change in the MD cells volume, while the latter, obtained from computational X-ray diffraction of reciprocal space maps, were used to evaluate the change in the lattice parameter. We show that <110> dumbbell SIAs have the largest Ω^{rel}, ~1.5 atomic volume (Ω_0); ½<111> and <100> interstitial dislocation loops exhibit a relaxation volume of ~0.905 Ω_0 and ~0.873 Ω_0 per extra-atom, respectively. C15 clusters of size 12 and 48 atoms show a W^{rel} of ~0.91 Ω_0 and ~0.98 Ω_0, respectively. Single vacancies are characterized by a negative Ω^{rel} (~-0.11 Ω_0) that exhibits increases to approach zero as vacancy clusters grow. Using these values, we predicted (with an error of maximum 2 %) the lattice strain in MD cells containing several types of defects, which indicates that the relaxation volume contributions can be summed up to estimate the change in the lattice parameter.

The proposed methodology is currently being applied to Ni, and will be further used in more complex compounds such as concentrated solid solution alloys, starting from equiatomic NiFe for which experimental data is being produced to compare with modelling predictions.

Abstract 284 WED-AR-RE-03-3 Invited Talk - Wednesday 12:30 PM - Pioneer IV

Novel Refractory High Entropy Alloys for Applications in Extreme Environments

Osman El Atwani[1], Andrew Alvarado[1], Kevin Baldwin[1], Saryu Fensin[1], Enrique Martinez[2]

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In the quest of new materials that can withstand severe irradiation and mechanical extremes for advanced applications (eg. fission reactors, fusion devices, space applications, etc.), design, prediction and control of advanced materials beyond current material designs become a paramount goal. W-based refractory high entropy alloys (HEAs) have been recently developed in the context of high temperature applications. Here, we present novel W-based refractory nanocrystalline and coarse grained HEAs and their performance to extreme environments. **In-situ** TEM thermal stability experiments,

mechanical properties and irradiation resistance to single and dual beam irradiations are assessed. The results are elucidated based on theoretical modeling combining ab initio and Monte Carlo techniques. The simulation (CALPHAD, DFT and Cluster Expansion) guided HEAs demonstrated outstanding irradiation resistance and high thermal stability and mechanical properties, establishing a breakthrough in the design of new materials for extreme environments.

Abstract 231 WED-AR-RE-03-4 Contributed Talk - Wednesday 12:30 PM - Pioneer IV

Interface effect of Fe and Fe_2O_3 on the distributions of ion induced defects

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The stability of structural materials in extreme nuclear reactor environments with high temperature, high radiation, and corrosive media directly affects the lifespan of the reactor. In such extreme environments, an oxide layer on the metal surface acts as a passive layer protecting the metal underneath from corrosion. To predict the irradiation effect on the metal layer in these metal/oxide bilayers, nondestructive depth-resolved positron annihilation lifetime spectroscopy (PALS) and complementary transmission electron microscopy (TEM) were used to investigate small-scale defects created by ion irradiation in an epitaxially grown (100) Fe film capped with a 50 nm Fe_2O_3 oxide layer. In this study, the evolution of induced vacancies was monitored, from individual vacancy formation at low doses (10^{-5} dpa) to larger vacancy cluster formation at increasing doses, showing the sensitivity of positron annihilation spectroscopy technique. Furthermore, PALS measurements reveal how the presence of a metal-oxide interface modifies the distribution of point defects induced by irradiation. TEM measurements show that irradiation induced dislocations at the interface is the mechanism behind the redistribution of point defects causing their accumulation close to the interface. This work demonstrates that the passive oxide layers formed during corrosion impact the distribution and accumulation of radiation induced defects in the metal underneath and emphasizes that the synergistic impact of radiation and corrosion will differ from their individual impacts.

Abstract 283 WED-AR-RE-03-5 Invited Talk - Wednesday 12:30 PM - Pioneer IV

Novel Refractory High Entropy Alloys for Applications in Extreme Environments

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In the quest of new materials that can withstand severe irradiation and mechanical extremes for advanced applications (eg. fission reactors, fusion devices, space applications, etc.), design, prediction and control of advanced materials beyond current material designs become a paramount goal. W-based refractory high entropy alloys (HEAs) have been recently developed in the context of high temperature applications. Here, we present novel W-based refractory nanocrystalline and coarse grained HEAs and their performance to extreme environments. **In-situ** TEM thermal stability experiments, mechanical properties and irradiation resistance to single and dual beam irradiations are assessed. The results are elucidated based on theoretical modeling combining ab initio and Monte Carlo techniques. The simulation (CALPHAD, DFT and Cluster Expansion) guided HEAs demonstrated outstanding irradiation resistance and high thermal stability and mechanical properties, establishing a breakthrough in the design of new materials for extreme environments.

Abstract 220 WED-PR-SP-09-1 Invited Talk - Wednesday 12:30 PM - Palomino

Observation of an elusive Near-Threshold Proton Resonance in 11B

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The study of near-threshold resonances in weakly bound systems is an exciting topic in experimental and theoretical nuclear physics since they provide important information on the interaction of discrete states with the continuum. Recent theoretical developments aim to describe the continuum interaction. However, questions on the behavior, structure, and properties of the many-body systems close to the particle emission threshold remain open, making the experimental studies of near-threshold states and its characteristics crucial for constraining the theoretical efforts. In particular, a near-threshold proton resonance in ^{11}B has long been sought since it would provide a less exotic explanation to the controversial observation of the unexpectedly large β−p+ branching ratio in ^{11}Be. In this talk, I will discuss a recent experiment carried out at the John D. Fox Superconducting Linear Accelerator Laboratory at Florida State University where the near threshold proton state was observed at a resonance energy of 11.44±0.04 in ^{11}B via the ^{10}Be(d,n)^{11}B reaction. The results and implications will be presented.

Abstract 221 WED-PR-SP-09-2 Invited Talk - Wednesday 12:30 PM - Palomino

Development of a Triton source at Florida State University

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[(3)]Physics, Florida State University, Tallahassee Florida, United States

At the John D Fox accelerator laboratory at Florida State University and in collaboration with the University of Tennessee Knoxville and Oakridge National Laboratory, we have installed a dedicated Multi - Source of Negative Ions by Cesium Sputtering (SNICS) with the intent to produce triton beams; this will allow one to perform unique nuclear physics experiments using tritons in regular kinematics and test details of nuclear theory. We have successfully loaded titanium cones with protium and deuterium in order to test titanium absorption of hydrogen in bulk, and to understand the output of the source in preparation for tritium loading. In this talk, the hydrogen loading technique, safety precautions, initial deuteron beam intensities and deuterium gas loads will be discussed as well as future plans and availability.

Abstract 67 WED-PR-SP-09-3 Contributed Talk - Wednesday 12:30 PM - Palomino

Advances in single barium ion capture and imaging for a barium tagging sensor for NEXT neutrinoless double decay searches

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The NEXT collaboration is pursuing a phased program to search for neutrinoless double beta decay($0\nu\beta\beta$) using high pressure xenon gas time projection chambers. The implementation of single barium daughter ion tagging is a possible new technology to dramatically enhance the sensitivity of xenon gas detectors. This approach would reduce radiogenic and cosmogenic backgrounds by orders of magnitude. I will present recent developments of single ion barium tagging technology based on single molecule fluorescence imaging (SMFI) using a novel high pressure gas microscope and custom-engineered organic fluorophores for dry functionality and an in-situ barium ion beam for sensor testing. This end-to-end test stand serves as a prototype sensor for integration into a future barium tagging high pressure xenon gas TPC experiment.

Abstract 241 WED-PR-SP-09-4 Contributed Talk - Wednesday 12:30 PM - Palomino

Updated ^{235}U Spectrum Measurement from the PROSPECT-I Data Set

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On behalf of the PROSPECT collaboration

PROSPECT is a reactor antineutrino experiment consisting of a 4-ton liquid scintillator antineutrino detector divided into an 11x14 array of optically separated segments. The detector was designed to probe the existence of sterile neutrino oscillations and precisely measure the antineutrino spectrum resulting from 235U fission. Data was taken in 2018 and 2019 with a first-generation detector called PROSPECT-I that was located on the Earth's surface roughly 7 m from the 85 MW, compact, highly-enriched High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory. This dataset has already had a substantial impact by placing stringent limits on sterile neutrino oscillations at the eV scale, setting new direct limits on boosted dark matter models, providing a precision 235U spectral measurement, and demonstrating unique neutrino detection capabilities. During the data collection period, information coming from a small number of PMTs had to be excluded causing an overall statistical impact on previous results. To recover this otherwise lost information, two new data analysis tools known as Data Splitting and Single Ended Event Reconstruction have been implemented resulting in a multi-period analysis with improved antineutrino event selection criteria. This presentation will review the impact of this new analysis effort in the measurement of the 235U spectrum, as well as the strategy for new oscillation and flux analyses.

This work is supported by the US DOE Office of High Energy Physics, the Heising-Simons Foundation, CFREF and NSERC of Canada, and internal investments at all institutions.

Abstract 187 WED-AA-IBTM-05-1 Invited Talk - Wednesday 2:30 PM - Arabian

The effect of precise and shallow helium implantation on materials

Peter_Hosemann, Mehdi_Balooch, Sarah_Stevenson, Minsung_Hong

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Helium ion effects in materials are a significant issue in numerus fission reactors (CANDU, FBR, etc) as well as fusion and spallation systems. Fast neutrons can create a significant amount of Helium in a material. In addition, Helium ions are created in fusion plasmas creating a helium impact on first wall materials in fusion. Therefore understanding Helium effects in material is key for the above mentioned application. In this work we utilize a Helium Ion Beam Microscope to perform Helium effect studies on materials. A new rapid evaluation technique is established shedding inside into helium effects in materials. A range of materials Cu, Ti, V, steels, and even bulk metallic glasses are studied using the rapid nano beam based implantation and subsequent characterisation techniques introduced. We are able to identify swelling an blistering mechanism as well as changes in mechanical properties due to the Helium implantation.

In addition, we utilize the nanobeam implantation to study the question how does Helium implantation affect the corrosion and oxidation on materials. We implanted stainless steel as well as pure iron using Helium and oxidize the samples subsequently. Post oxidation TEM and AFM measurements show that the two distinct regions of enlarged cavities are

formed in the metal while no cavities are formed in the newly grown oxide. The data suggest that the Helium implantation promotes the formation of Kirkendall pores as well as larger cavities due to Helium bubble coalescence.

Abstract 96 WED-AA-IBTM-05-2 Invited Talk - Wednesday 2:30 PM - Arabian

Adding "color" to Helium Ion Microscopy images

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Helium Ion Microscopy (HIM) is well known for its high resolution imaging and nano fabrication capabilities(1-3)However, the created images are black and white images presenting a mixture of material and topography contrast. While these images are beautiful and of high importance for several research fields they do not include all the information that could in principle be harvested from the specimen using HIM.

Here, I want to summarize the attempts of my group over the last decade to add "color" to HIM images. In this context I will show how we exploit primary and secondary particles generated during the ion solid interaction to obtain elemental and structural information from the sample. The key element here is that the information is always collected as a map and in this way can be combined with the high resolution surface image to gain additional insight.

I will briefly cover results obtained using ionoluminescence [4], back scatter spectroscopy [5], secondary ion mass spectrometry [6] and channeling of electrons and ions in backward [7] and forward direction (8)All methods have advantages and drawbacks but can achieve lateral resolutions between 10 nm and 100 nm.

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Design of an electrostatic focusing system for low MeV multi-ion micro-beam

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Heavy ion therapy (HIT) typically using ions ranging from helium to carbon is currently the most advanced form of cancer radiotherapy. As our understanding of how charged particles deposit their energy into matter improved (Bragg Peak Energy deposition), the advantages offered by Heavy ions over conventionally used X-rays and even protons became apparent.

In addition to the already known advantages, recent studies have shown how the DNA damage induced by a treatment procedure which combines multiple ion types and energy range produce a non-additive higher effect than what a single ion would produce for the equivalent net dose. This has sparked significant interest in the community and the effort to bridge the gaps in our understanding for the entire reaction process that takes place via Heavy Ion induced radiation has been a top priority. To annotate this process, radiobiological studies need to be conducted via very precise microbeams capable of targeting specific areas inside a cell, hence limiting the beam spot to within a few hundred nanometers. In addition, it would be critical that the particle delivery system achieves the same focused final beam irrespective of the particle it is focusing on. This ensures that the result is independent of the dose delivery system and solely depends on the type of Ion being studied.

Traditionally, high focusing microbeams are magnetic in mature which limits their application in radiobiological studies as only one Ion type can be focused for a certain magnetic lens field strength. Electrostatic lens can focus multiple Ions but have limited focusing capabilities due to their inherent higher aberrations.

In our efforts we developed an Electrostatic microbeam capable of achieving high focusing strength and minimizing the produced aberrations. The investigation was performed using the simulation tools of SIMION 8.1 (high accuracy but low efficiency) and GICOSY (contra) and WinTrax. The numbers, lengths, intervals and applying voltages of the composition lens and aperture-lens distance (D_{AL}) for a given input beam were studied and optimized. The performance of the optimized systems was compared with that of the state-of-art electrostatic quadrupole sextuplet (EQS) system, in the aspects of system length (L_s), working distance (D_w), demagnification factor (D_f), chromatic and spherical and parasitic aberrations.

Two electrostatic quadrupole lens systems composed of a quadruplet (EQQ) and a triplet (EQT) were obtained in our optimization for a 3MeV/q input proton beam with input beam diameter of **30μm** and angular divergence of **0.0067mrad.** We employed the 'Russian Symmetry' (+A -B +B -A) to configure the Polarization of the lenses. After optimizing all the variable parameters, the optimal voltage values were found to be **5200V** (+A) and **-3686V** (-B) and all four quadrupole lenses were of equal length (92 mm). During the optimization process we realized that by inducing a drift distance of 300 mm between the second and third lens the beam can be expanded broadly at the entrance of the third lens to realize a strong focus overall. Each set of quadrupoles is housed between a pair of grounding plates with each plate 3 mm in length to maintain a separation of electric fields between adjacent electrodes. The EQQ provides a de-magnification of **~54** at a working distance of 98.4 mm. For EQT the optimal lengths for the three lenses were obtained as 155, 115 and 55 mm respectively with corresponding excitation potentials of **-4684**, **1957** and **-4684 V**. The optimized EQT lens system can focus different ions for an energy-charge ratio of 3 MeV/q into a beam spot smaller than **200 nm** at a working distance of 130.2 mm producing a high demagnification of **~110**. The EQT lens system initially suffered from high aberrations as Electrostatic lenses generally do. To fix this a special Octupole stigmator was designed and installed after the last triplet which significantly reduced the produced aberrations while having minimal effect on the focusing strength. The aberration cross terms are small and the overall performance of the system quantified by Q value is **~24**. The system has a compact design, in a total length around 0.5 meter. By increasing the distance between the divergence aperture and the first lens to 1 meter, the focusing beam size could be further reduced with an improved **Q** value of **~33**.

Abstract 183 WED-AA-IBTM-05-4

Contributed Talk - Wednesday 2:30 PM - Arabian

Ion and neutral time-of-flight spectroscopy for deciphering the composition and structure of plasma-facing materials

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Low energy ion scattering (LEIS) and direct recoil spectroscopy (DRS) both rely on ion beams at energies < 20 keV to probe the composition and structure of surfaces. Like most surface analysis techniques, both LEIS and DRS are used at low pressures typical of ultra-high vacuum systems, usually 10^{-4} Pa or less. In this study, we discuss modifications to these techniques to extend their range by several orders of magnitude. The eventual goal of this work is to enable these techniques to provide information on surfaces during low flux ion and plasma bombardment.

As a demonstration of our approach, we have constructed a prototype instrument for time-of-flight (TOF) spectroscopy consisting of a differentially-pumped ion source and flight tubes. For these measurements, we relied on a pulsed alkali ion source (~40 ns rise time) with customized ion optics to probe a variety of targets. This equipment was attached to an ultra-high vacuum chamber with two time-of-flight tubes mounted at 65°, and 160° relative to the incident ion beam to detect both forward and back-scattered particles simultaneously. Initial characterization of 10 keV Li+ scattered from Au, W, Pd, Ni, and Al surfaces at pressures of 5×10^{-2} Pa and above revealed minimal attenuation of the scattered signal and good mass resolution. Preliminary results from these experiments will be presented; additional work is planned to study chemisorbed hydrogen on different metal surfaces of interest for plasma-facing materials R&D.

A potential advantage of the instrumentation as discussed above is its compact size in comparison with the instrumentation needed for high energy ion beam analysis (e.g. Rutherford backscattering), making it easier to implement on smaller systems. The lower incident energy also improves the surface sensitivity of the diagnostic, as the scattered and recoiled particles contain information on only the top few monolayers of the surface. In addition, the large scattering cross sections at lower energies increases sensitivity and enable changes in surface composition to be observed at relatively short intervals (~5 min. to acquire a spectrum.) [1]

[1] R. D. Kolasinski, J. A. Whaley, and D. Ward, **Surf. Sci. 677** (2018) 176.

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Abstract 52 WED-AC-TD-01-1

Invited Talk - Wednesday 2:30 PM - Pioneer III

Neutron-gamma technologies for carbon sequestration assessments

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Methods of rapid **in-situ** soil carbon determination are desirable for assessing land management decisions that could enhance carbon sequestration and have potential relevance in emerging carbon credit markets. One promising technology is neutron gamma analysis, which registers gamma rays appearing from neutron irradiation of soil to determine soil carbon content. Since this method produces a complicated mixture of gamma rays appearing from neutron interactions with various soil elements, extraction of gamma rays directly connected with soil carbon is the main difficulty in this analysis. Different modes of measurement can be utilized to overcome this issue. Pulsed neutron soil irradiation and gamma spectra

acquisition during and between neutron pulses is used in Pulsed Fast Thermal Neutron Analysis (PFTNA). This method allows separation of the inelastic neutron scattering (INS) spectrum from the thermal neutron capture (TNC) spectrum. In the net INS spectra, the peak with a centroid at 4.44 MeV is attributable to carbon and can be used for determining soil carbon levels. Based on this PFTNA method, a mobile system for determining soil carbon was designed and constructed to be suitable for towing across agricultural fields. This mobile inelastic neutron scattering system (MINS) consists of a MP320 pulsed neutron generator (Thermo Fisher Scientific Inc.), sodium iodide gamma detectors (Scionix) with thermostatic housing, neutron detector(s), GPS, a data acquisition system (Vega board, XIA LLC), a power system to provide autonomous work, and an operating computer. The MINS system design, spectral acquisition processes, and strategies for acquiring carbon data in the field will be discussed in this presentation. Soil carbon determination results and mapping of actual agricultural fields will also be shown and discussed.

Associated particle imaging (API) or tagged neutron (TN) technique is another possible neutron-gamma method for detecting soil carbon **in-situ** or in bulk soil samples (~30-50 kg). Using this technique, measurements in alpha-gamma coincidence mode produce a neutron stimulated INS gamma response primarily from the sample. For this reason, this carbon measurement method has a high signal-to-noise ratio and sensitivity comparable to PFTNA. Our system for TN mode measurements was constructed using an API120 (Thermo Fisher Inc.) neutron generator (with built-in alpha gauge), LaBr(Ce) gamma detector (Ø7.62cm × 25.4 cm crystal size; Saint-Gobain), and a DAQ system with a Pixie-Net (XIA LLC) module working in the coincidence mode. This setup is currently being tested on large samples prior to further testing in field applications. The main advantage of TN mode is that the measured INS spectra are from the sample with no gammas from surrounding objects and measurement equipment. Because of this advantage, the amount of each component in the sample (based on decomposition of measured spectra components) can be defined. For sand-carbon mixture analysis, spectra of components [silicon, oxygen (water), carbon (graphite or coconut shell)] and spectra of mixtures were measured in the TN mode. Assuming that gamma spectra of mixtures are the sum of the gamma spectra of components with weight coefficients (proportional to fraction of components in mixture), the content of mixtures can be found using the least square method. Good agreement was found when comparing these sand-carbon mixture results with PFTNA carbon determinations (based on peak area calculations and previously created calibration dependence) and with chemical analysis results. This agreement supports the possible application of the TN method for field carbon determinations as a promising alternative to the current PFTNA method. Other advantages and disadvantages of the TN method in field applications will also be discussed.

Abstract 132 WED-AC-TD-01-2 Contributed Talk - Wednesday 2:30 PM - Pioneer III

Quantifying Carbon Sequestration using Associated Particle Imaging

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Plans to achieve net-zero carbon by 2050 include carbon sequestration in agricultural soils. However, no scalable tools currently exist that can quantify soil carbon concentrations. To be able to utilize the large potential of soils to sequester carbon and for farmers to get paid for their effort, new tools that allow accurate measurement of carbon in soil are needed. We are developing a portable, non-destructive measurement system for fast analysis of carbon distributions in volumes of soil. Our approach measures inelastic neutron scattering events. The instrument consists of a deuterium-tritium (DT) neutron generator, an alpha particle detector, and gamma ray detectors. The DT neutron generator works by accelerating a mixture of deuterium and tritium ions towards a titanium target where DT fusion occurs. This reaction emits an alpha particle and a neutron with a certain angle between the two, which is dictated by its reaction kinematics. The alpha particle is then detected with a scintillator (YAP) and a position-sensitive photomultiplier tube, which allows us to calculate the trajectory of the associated neutron, effectively "tagging" it. If a tagged neutron induces an inelastic scattering reaction on a carbon-12 nucleus present in the soil that populates its first excited state at 4.4 MeV, a gamma ray with the same energy is emitted. Gamma ray detectors (LaBr and NaI) are located close to the inspected soil, and if this gamma ray is detected in coincidence with the alpha particle, it is possible to determine the location of the carbon atom. Accumulating many events allows us to calculate the 3D carbon distribution in a region of 50 cm × 50 cm × 30 cm (depth) of the soil. Apart from carbon, our instrument also measures the distribution of other elements in the soil, such as, Al, Fe, Si, O. Measurement durations vary from a few minutes to hours depending on the desired precision of carbon concentration and depth of soil layer inspected. We achieved a resolution of 4 cm in XY and around 6 cm in depth at a distance of 60 cm from the neutron generator. We will report on our system design and measurement results, including measurements of large soil volumes, and outline plans to measure acre-sized fields.

Abstract 162 WED-AP-MA-06-1 Invited Talk - Wednesday 2:30 PM - Quarter

Accelerator-based BNCT in Finland

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Helsinki University Hospital (HUS) has long been a leading center of Boron Neutron Capture Therapy (BNCT) research, carrying out a successful reactor-based clinical BNCT program during almost 13 years from 1999 to 2012, when over 300 BNCT treatments were given to 249 patients. The program was cut short as the reactor became unavailable for continued treatments. To resolve this issue, HUS entered into a partnership with Neutron Therapeutics Inc. in 2016 to create an accelerator-based BNCT center at HUS. Neutron Therapeutics nuBeam system includes a single-ended electrostatic Cockcroft-Walton type proton accelerator with proton beam energy 2.6 MeV and the maximum current 40 mA. The accelerator is operating at continuous mode. The neutron therapy system incorporates an image guided robotic patient positioning system, an on-line neutron beam monitoring system, a treatment control software and a treatment planning software designed for BNCT. The design and construction of a new facility on the HUS hospital campus has been completed, and the nuBeam system has been installed. Extensive accelerator and neutron beam testing has been carried out, completing the development of the nuBeam hardware and software suite and confirming its readiness to treat patients. The current status of the program and future clinical plans will be summarized.

Abstract 165 WED-AP-MA-06-2 Contributed Talk - Wednesday 2:30 PM - Quarter

Neutron Beam System for Accelerator-Based BNCT

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Over the last decade, Accelerator-Based Boron Neutron Capture Therapy (AB-BNCT) has enjoyed exponential growth. Among a variety of accelerator systems used for generating neutron beams for AB-BNCT, electrostatic proton accelerators are proven to be simple, reliable, and cost effective.

The Neutron Beam System (NBS) offered by TriAlpha Life Sciences (TLS) is based on the tandem architecture of electrostatic accelerators. Double action of the accelerating voltage and ion injector at the ground potential are among technical advantages of the tandem accelerators. TLS NBS is based on a prototype of the tandem accelerator developed at the Budker Institute of Nuclear Physics, Russia. The commercial version has both proton beam energy and proton current increased to clinically relevant levels. The boosted-up performance was achieved by introduction of a number of innovations. First TLS NBS for clinical use is installed in Xiamen, China, as a part of NeuPex AB-BNCT System designed and developed by Neuboron Medical Group. This version of NBS is designed for three treatment room configuration. At the present state, commissioning of the first treatment room is complete. The system is currently undergoing regulatory tests and clinical trials. Design highlights and achieved performance will be discussed.

Abstract 281 WED-AP-MA-06-3 Invited Talk - Wednesday 2:30 PM - Quarter

Current status of Sumitomo BNCT system NeuCure

Hiroshi Tsutsui

Sumitomo Heavy Industries, Ltd., Shinagawa City Tokyo, Japan

Sumitomo Heavy Industries (SHI) has produced medical devices, such as PET Tracer Production Systems and Proton Therapy Systems, based on a-half-century history of manufacture of particle accelerators. BNCT (Boron Neutron Capture Therapy) is a treatment method that has been researched since the 1950s with the aim of curing intractable cancer. SHI has developed an accelerator-based BNCT system, and in 2020, Sumitomo BNCT system named "NeuCure" received medical device approval in Japan for unresectable locally advanced/recurrent head and neck cancer.

With a safety and reliable system using beryllium targets, "NeuCure" continues to provide neutron beams for medical treatment. Including the clinical trials, About 350 patients have been treated with our BNCT systems. SHI strives to improve the systems based on these experiences.

As one of the results, in 2022, new extended collimators approved. The use of extended collimators makes it possible to flexibly set the patient's position during treatment, and more efficient treatment with a more comfortable posture is expected. In addition, a new project to introduce BNCT system to Pengbo (Hainan) Medical Technology Co., Ltd. in Lecheng International Medical Tourism Pilot Zone, Boao City, Hainan Province, China started, where is a special deregulated zone aimed at promoting medical tourism, with priority given to import of pharmaceutical and medical devices.

The current status and future prospect of "NeuCure" will be reported.

Abstract 272 WED-AP-MA-06-4 Invited Talk - Wednesday 2:30 PM - Quarter

An Approach for a Boron Proton Fusion Therapy (BPFT) - Assessment of Alpha Particles

Premkumar Saganti[1], Sunil Krishnan[2]

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The boron proton fusion therapy (BPFT) have been studied and discussed since the early 1960's by the both nuclear theoretical and experimental scientists. Three alpha particles are emitted after the reaction between a proton (1 H) and a boron particle (11 B). These three alpha particles can provide significant damage to the tumor cell, just as in the case of one alpha particle of the boron neutron capture therapy (BNCT). Theoretically, in the case of BPFT, the therapy efficacy per incident particle is three times greater than that of BNCT.

Refently, we studied the boron proton fusion utilizing the nano boron (11 B) particles developed by our team with the proton beam with 80 MeV.at the UT MD Anderson proton therapy center and we utilized our 1.67 micron / pixel radaition detector system to asess and characterize the released alpha particles in the BPFT reactions.

We present our prelimicary results and observations for such a BPFT development.

Abstract 282 WED-AP-MA-06-5 Invited Talk - Wednesday 2:30 PM - Quarter

Prompt gamma ray imaging using cadmium telluride detectors for boron neutron capture therapy

Sang Cho

MD Anderson Cancer Center, Houston TX, United States

For successful boron neutron capture therapy (BNCT), B-10 concentration and distribution in the tumor (as well as in the critical organs) must be determined non-invasively. Current methodologies use radiolabeled boronophenylalanine (F18-BPA) with PET imaging to visualize the pattern and intensity of BPA uptake by the tumor and surrounding tissues. Due to the expense of the radiolabeled compound that serves as a surrogate for BPA, the need for an additional day for the imaging study, and the cost of PET imaging, the use of F18-BPA PET is not routine in current BNCT practice. An approach, based on the detection of prompt gamma (PG) rays from the BNC reaction, appears to be attractive, because it can be implemented within the BNCT setup without using the radiolabeled F18-BPA. We investigated the feasibility of this approach with cadmium telluride (CdTe) detectors by performing Monte Carlo (MC) simulations using the Geant4 MC toolkit. Our MC study demonstrated the detectability of PG rays from the BNC reaction using CdTe detectors under the conditions closely mimicking realistic accelerator-based BNCT scenarios. It also showed that clinically acceptable quantitative imaging of B-10 distribution could be performed utilizing the PG ray signals from the BNC reaction.

Abstract 275 WED-AP-MA-06-6 Invited Talk - Wednesday 2:30 PM - Quarter

Developing novel boron agents for BNCT

Sunil Krishnan

Radiation Oncology, UT Health Science Center Houston, Houston Texas, United States

My talk will expand on current and future boronated compounds that can be preferentially taken up by cancer cells rather than normal cells and thereby aid boron neutron capture therapy, a binary therapy where epithermal neutrons created by bombardment of lithium and berylium targets with proton accelerators interact with boron-10 administered systemically to patients so as to accumulate in tumors and thereby generate high linear energy transfer helium and lithium ions in cancer cells. The efficacy of such accelerator-based neutron capture therapy depends on achieving tumor-specific accumulation of boron-10 in sufficient quantities to trigger BNCT. First-generation compounds achieved a roughly 4:1 differential between tumor and normal tissues. Newer generations of boronated compounds can possibly improve upon this and thereby greatly enhance therapeutic efficacy and potentially extend the reach of BNCT to deeper seated tumors. My talk will focus on the potential for novel drug development in this space - past, present, and future.

Abstract 21 WED-AR-RE-04-1 Invited Talk - Wednesday 2:30 PM - Pioneer IV

Effects of Electronic Energy Loss on Disordered Oxide Perovskites

William J Weber[1], Gihan Velisa[2], Eva Zarkadoula[3], Ritesh Sachan[4], Yanwen Zhang[3]

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[(2)]Horia Hulubei National Institute for Physics and Nuclear Engineering, Măgurele Ilfov, Romania
[(3)]Material Sciences and Technology, Oak Ridge National Laboratory, Oak Ridge Tennessee, United States
[(4)]Mechanical and Aerospace Engineering, Oklahoma State University, Stillwater Oklahoma, United States

Oxide perovskites exhibit fascinating properties that identify them as key materials for the next generation of multifunctional devices, and ion-beam modification can be used to tune their functionality. While it is well-established that atomic-level defects are created by elastic energy transfer, S_n, from charged particles to atomic nuclei, the effects of inelastic energy loss, S_e, to target electrons is more complicated. High-energy ions with S_e values above a threshold interact synergistically with pre-existing disorder in $SrTiO_3$ and $KTaO_3$ to form amorphous nanotracks along ion trajectories at 300 K. The nanotrack cross-sections increase with S_e and the level of pre-existing disorder, and the inelastic energy loss threshold, S_{et}, decreases with increasing level of disorder. Application of the analytical thermal spike model suggests a

decrease in effective melting temperature and increase in efficiency of track formation with increasing disorder. Molecular dynamics simulations combined with the inelastic thermal spike model confirm that the formation of these amorphous tracks is due to melt-quenching along the ion trajectory. While high energy ions contribute to damage production above S_{et}, the effects of inelastic energy loss on pre-existing disorder below S_{et} have not been studied in detail. To investigate this, pre-damaged surface layers of $SrTiO_3$ have been irradiated with 200 keV electrons, 2 MeV He, 1.2 MeV C, 5 MeV C and 12 MeV O ions, and pre-damaged surface layers of $KTaO_3$ have been irradiated with 5 MeV C and 12 MeV O ions. The results indicate two distinct regimes of ionization-induced recovery in $SrTiO_3$ and only a single recovery regime, thus far, in $KTaO_3$. While melt-quenching does not occur for these ions, the inelastic thermal spike for C and O ions, with S_e between 1.6 and 3 keV/nm, causes sufficient local heating via electron-phonon coupling to induce defect recovery in both $SrTiO_3$ and $KTaO_3$, which has been confirmed by MD simulations for the case of $SrTiO_3$. At lower values of S_e, the efficiency of defect recovery decreases by several orders magnitude for 2 MeV He ions and 200 keV electrons in $SrTiO_3$, and this recovery is attributed to local electronic excitations that enhance defect mobility. In undamaged $KTaO_3$, irradiation with 200 keV electrons results in ionization-induced damage formation.

Abstract 203 WED-AR-RE-04-2 Invited Talk - Wednesday 2:30 PM - Pioneer IV

High-Entropy Carbide Ceramics in Nuclear Energy Applications

Bai Cui[1], Fei Wang[1], Lanh Trinh[1], Xueliang Yan[1], Yongfeng Lu[1], Kaustubh Bawane[2], Cody Dennett[2], Zilong Hua[2], Linu Malakkal[2], Lingfeng He[2]

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The concept of "high entropy" has created promising opportunities for the design of new ceramic materials for extreme environments encountered in advanced nuclear reactors. High-entropy carbide ceramics (HECCs) are a family of transition metal carbides with multiple metal elements in an equal or near-equal atomic ratio in the cation position but forms a stable single-phase rock salt structure. The compositional complexity in HECCs can induce the atomic-level disorder, significant lattice distortion, and unique physical properties such as higher hardness, lower thermal conductivity, and improved oxidation resistance than the binary transition metal carbides. Since 2018, our team has developed spark plasma sintering and selective laser sintering processes for the synthesis and advanced manufacturing of HECCs, reported their thermal and mechanical properties, and investigated their irradiation damage mechanisms. This talk will focus on our experimental research activities to reveal fundamental mechanisms governing the processing-microstructure-property relationship in these novel ceramic materials in extreme environments.

Abstract 238 WED-AR-RE-04-3 Invited Talk - Wednesday 2:30 PM - Pioneer IV

Exploration of the combined effects of displacement damage and total ionizing dose degradation in the LM741 operational amplifier using Si ion and electron irradiation

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Understanding semiconductor device and circuit degradation modes to displacement damage and total ionizing dose is important for multiple defense, space, and industrial applications. It is well known that heavy ion irradiation can reproduce neutron like displacement damage in semiconductors and electrons can emulate ionization by x-ray or gamma environments. Heavy ions can be used to quickly baseline the radiation response of devices or circuits prior to high fidelity tests such as those performed in nuclear reactors while minimizing target activation. Likewise, low energy electrons (≤100 keV) can be used to provide a cheaper and faster method to explore the effects of high dose rate ionization prior to testing with LINAC electron accelerators or other short pulse sources.

This study will discuss the use of Si ion and electron irradiation as surrogate environments for reproducing displacement damage and ionization in neutron and gamma environments, respectively, in commercial linear bipolar silicon technology. The LM741 operational amplifier was selected for this study as a representative of general Si linear bipolar technology. The circuit is composed of vertical npn bipolar junction transistors (BJT), lateral and substrate pnp BJTs, multiple resistors and

a capacitor. The circuit die was cross-sectioned and analyzed with scanning electron microscopy to identify device specific junctions and modeling was performed to optimize ion energy for maximum vacancy production in the base emitter junction of the vertical npn transistors. The electron beam penetrates through the transistors to the substrate. Input bias current, slew rate, and radiation induced transients were monitored to understand specific damage modes and derive transistor gain degradation. Input bias current was measured to quantify degradation of the input stage and the circuit slew rate was measured to quantify degradation of the output stage. Degradation for both stages was observed under individual and combined ion and electron irradiations.

The LM741 was first irradiated with ions or electrons separately to understand circuit degradation caused by displacement damage or ionization. For ion or electron only irradiation, degradation of the input bias current and slew rate was monotonic with displacement damage up to circuit failure (defined as an inability to switch the output), but non-monotonic with ionization. The monotonic deviation caused by displacement damage is due to gain reduction in the vertical npn BJTs whereas ionization produces larger gain reduction in the lateral pnp BJTs than the substrate pnp or vertical npn BJTs. This gain reduction caused circuit compensation of the input stage bias current, modification of current supplied to the capacitor, and inability to shift the voltage level of the amplifier resulting in a latched output.

Next, combined ion and electron irradiations were performed to observe differences when compared to separate environments and elucidate synergistic behavior. For combined ion and electron irradiation, synergistic behavior was defined as a deviation from the linear sum of ion and electron irradiation for a particular circuit metric. Negative synergistic behavior was defined as less degradation for combined irradiation when compared to the linear sum of ion and electron only degradation, and positive behavior was defined as a greater degradation when compared to the linear sum. In combined ion and electron irradiation the input bias current showed a negative synergistic non-monotonic response. This effect is caused by circuit compensation of the input stage bias current as observed with electron only irradiation. Under combined ion and electron irradiation, slew rate showed positive synergistic behavior. This behavior is attributed to enhanced gain degradation of the lateral pnp BJTs under combined irradiation. These results show that synergistic effects may be present in combined displacement damage and ionization environments such as reactor and space systems that use integrated circuits with linear bipolar Si technology. Thus, this behavior could be missed in simple serial testing of displacement damage followed by ionization or vice-versa.

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Abstract 49 WED-AR-RE-04-4 Contributed Talk - Wednesday 2:30 PM - Pioneer IV

Radiation effects on interfacial phenomena in ceramics

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Interfaces are known to play an important role in controlling a plethora of properties relevant to structural materials, including mechanical strength, toughness, and corrosion resistance. However, the atomic and chemical structures of interfaces are not static when the material is driven out of equilibrium by exposing it to high temperature, stress, or irradiation. In this talk, I will discuss the effects of radiation on interfaces in SiC-based materials. I will demonstrate that radiation-induced segregation (RIS) of constituent elements is possible in ceramics, even when they form line compounds, and I will discuss the impact of RIS on corrosion resistance.

Finally, I will demonstrate that nano-engineering of interfaces can enhance the properties, of ceramic materials such as fracture toughness, phase stability, under ion implantation.

Abstract 135 WED-PR-AMP-02-1 Invited Talk - Wednesday 2:30 PM - Kincaid (Hybrid)

Dissociative Electron Attachment to Biomolecular Systems

Sylwia Ptasinska

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The processes of electron scattering on molecular systems, particularly on biomolecules, have been a focus of experimental and theoretical efforts over the last two decades (1)These fundamental studies aim to describe complex cellular mechanisms involving low-energy electrons (LEEs), one of the most abundant species produced by high-energy ionizing radiation. Therefore, the knowledge of molecular states of biomolecules upon electron interactions is of great importance in finding the role and contribution of LEEs in radiation damage. In addition, many of the processes can lead to fragmentation of biomolecules, which is essential to understand to provide possible scenarios of radiation damage in the cell. One of the processes which result in fragmentation through resonant electron capture into one of the metastable valence states of a molecule is dissociative electron attachment (DEA). However, despite many gas-phase DEA studies on various biomolecular systems, including the constituents of DNA, RNA, and proteins, their resonance characterization remains challenging.

Therefore, our recent work focuses on amides that can be considered models for larger biologically relevant molecules, that are peptides. The choice of these simpler systems containing amide bonds was dictated by the possibility of performing high-level electronic structure calculations and studying them in the gas phase.

In this talk, we present our findings from experimental and computational studies of the gas-phase DEA to some prototypical peptide molecules (2)In addition to careful investigations of all fragments formed via DEA, our great focus has been on amide bond rupture. Interestingly, a double-resonant structure was observed at similar energies in the ion yields for all ions resulting from the amide bond cleavage. Several plausible mechanisms of electron attachment were considered computationally to characterize these structures. Based on our calculations, these resonances can be assigned to core-excited dipole-supported resonances populated upon DEA [3].

Furthermore, our recent technical development on neutral detections from DEA has opened exciting possibilities to probe fragmentation channels that are significant for providing the ultimate answer on how important LEEs are in radiation damage in the cell [4,5].

Acknowledgments: This work was supported by the U.S. Department of Energy Office of Science, Office of Basic Energy Sciences under Award Number DE-FC02-04ER15533.

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Towards the Ionizing Radiation-Induced Bond Dissociation Mechanism in Guanine and DNA Fragmentation: A Density Functional Theory Simulation

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The radiation-induced damages in bio-molecules are ubiquitous processes in radiotherapy, radio-biology and critical to space-projects. In this study we present a precise quantification of the fragmentation mechanisms of deoxyribonucleic acid (DNA) and the molecules surrounding DNA such as oxygen and water under non-equilibrium conditions using the first-principle calculations based on density functional theory (DFT). Our results reveal the structural stability of DNA bases and backbone that withstand up to a combined threshold of charge and hydrogen abstraction owing to simultaneous direct and indirect ionization processes. We show the hydrogen contents of the molecules significantly control the stability in the presence of radiation. This study provides comprehensive information on the impact of the direct and indirect induced bond dissociations and DNA damage and introduces a systematic methodology for fine-tuning of the input parameters necessary for the large-scale Monte Carlo simulations of radio-biological responses and mitigation of detrimental effects of ionizing radiation.

Abstract 112 WED-PR-AMP-02-3 Invited Talk - Wednesday 2:30 PM - Kincaid (Hybrid)

Universal empirical and theoretical fits for K x-ray production cross sections

Gregory Lapicki

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The relevance of x-ray production cross sections (XRPCS) and the related ionization cross sections (ISC) in many research areas has been described at length and analyzed in detail [1]. X-ray emission cross sections by ion impact are a relevant input in many areas such as studies of track structure in biological matter. Particle Induced X-ray Emission (PIXE) strongly requires trustworthy databases for XRPCS and/or reliable predictions of inner-shell ionization theories as periodically evaluated in Monte Carlo Geant4 simulations [2].

To check if theories are accurate across the periodic table of elements and a large range of projectile energies, equally comprehensive databases are essential and a universal fit for them is desired..

For each target element, the **compiled XRPCS** [1] follow a single curve when plotted versus the ratio of the proton velocity v_1 to the orbital velocity of $v_{2L}=Z_{2L}/n$ of the inner-shell electron. Furthermore, for all elements XRPCS peak at $\sigma_{LX}^{max}(Z_{2L})$ when $v_1 = v_{2L}$. With $v \equiv v_1/v_{2L}$, a **universal fit** to all compiled data $\sigma_{LX}= \sigma_{LX}^{max}(Z_{2L})\cdot\exp[-(1+a_1Z_{2L})v^2+a_2v^7]$ is made with just two adjustable parameters $a_1=0.00484$ and $a_2=0.005$. The predictions of the ECUSAR theory [3] can be also fitted in a similar fashion as done recently based on recently updated data and the revised universal empirical fit [4]. With a standard deviation of 29%, 97% of these ratios are within a factor of 2 from the ideal ratio of 1.00 .

For this meeting,

universal empirical and theoretical fits to updated database will be reviewed as it was done the L shell [4],

over three decades old tables of K-shell XRPCS [9] will be updated with a new compilation,

similar to the L shell, universal empirical and theoretical fits to these updated data will be presented for the K shell.

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Abstract 266 THU-PS-PR-01-1 Plenary Talk - Thursday 9:00 AM - Quarter

Radioactive atoms and molecules for nuclear science

Ronald Fernando Garcia Ruiz

Deoartment of Physics, Massachusetts Institute of Technology, Cambridge MA, United States

Precise knowledge of the interaction between the atomic nucleus and the electrons that are bound to it allows the exploration of physical phenomena relevant to a wide range of energy scales. Atoms and molecules containing nuclei with extreme proton-to-neutron ratios can be artificially created to enhance and study particular nuclear phenomena. Hence, precision measurements of these systems can offer unique and complementary insights into the properties of the atomic nucleus, nuclear matter, and the fundamental particles and forces of nature. In this talk, I will present recent highlights and perspectives from laser spectroscopy experiments of these exotic species.

Abstract 43 THU-AP-IA-03-1 Invited Talk - Thursday 10:15 AM - Pioneer III

Laboratory Scale Light Sources

Alex Murokh

RadiaBeam Technologies, LLC., Santa Monica CA, United States

There is a continuously growing demand for brighter light sources in a variety of industrial, medical, and scientific applications. Accelerator technology is widely represented in this broader space as the industrial linacs are ubiquitous and produce inexpensive broadband gamma rays for many practical applications, while the accelerator driven synchrotron light sources and X-ray free electron laser (XFEL) facilities provide high purity tunable light for scientific research and high added value applications, such as drug discovery. Yet, there has always been an interest in the intermediate accelerator based light sources, which would bring to the users a synchrotron-quality light but in a compact laboratory-scale form factor. This paper summarizes the potential applications needs and the required compact light sources characteristics, in the context of which it reviews the recent progress, opportunities, and challenges in the development of the Inverse Compton Scattering (ICS) and compact XFEL light sources. The specific examples presented include two R&D programs currently in active experimental development by RadiaBeam and collaborators: one for a high flux ICS gamma ray source, and another for a compact high electron-to-light conversion efficiency FEL.

Abstract 184 THU-AP-IA-03-2 Invited Talk - Thursday 10:15 AM - Pioneer III

Extremely Brilliant Compton Sources and Potential Applications

Christopher P. J. Barty[1,2]

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A new generation synchrotron radiation sources which operate with lower emittance electron beams is emerging. These systems can produce extremely brilliant x-ray outputs which have led to some remarkable demonstrations of whole organ imaging at the cellular level via propagation-based phase contrast imaging. In parallel a new generation of x-ray sources based on advanced concepts for laser-Compton scattering are poised to create similar if not higher brilliance outputs from machines with compact footprints of a few meters. This presentation will review the activities in Irvine, California to create these next generation extremely brilliant Compton sources (EBCS) via novel Compton scattering architectures based on x-band linear accelerator and ultrahigh repetition rate laser technology. The presentation will introduce potential medical and industrial applications of EBCS technology.

Abstract 42 THU-AP-IA-03-3 Invited Talk - Thursday 10:15 AM - Pioneer III

Overview of high-brightness light sources operating in an X-ray photon energy range

Timur Shaftan

National Synchrotron Light Source - II, Brookhaven National Laboratory, Upton New York, United States

Modern X-ray sources play a key role in scientific research. Brightness of X-ray beams defines spatial and spectral resolution of experimental techniques and set the frontier of discoveries in physics, chemistry, material science, medicine and biology.

In the past several decades we witness a worldwide trend in increasing brightness of sources in the range from several to tens of keV. The advances in capabilities of laser-like sources in X-ray range hinge on developments in accelerators, conventional lasers and short-wavelength light optics.

In this presentation we will first define the brightness and related figures of merit. Next we will discuss the growth of capabilities of the bright light sources and follow up with corresponding examples ranging from synchrotron sources and FELs to these employing HHG and Compton effects.

Abstract 82 THU-AR-ISM-06-1 Invited Talk - Thursday 10:15 AM - Appaloosa (Hybrid)

Nanopatterning 2D semiconducting layers for large-scale photon harvesting and nanoelectronics

Maria Caterina Giordano, Francesco Buatier de Mongeot

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Two-dimensional (2D) Transition Metal Dichalcogenide semiconductors (TMDs) have attracted diffuse interest due to their exceptional optoelectronic properties (1)However, the inherent low photon absorption of the atomic layers demands novel light coupling schemes. There is also an urgent request to scale up the lateral size of the 2D layers, so far limited to micrometer scale flakes, and to engineer their shape at the nanoscale.

Here the large-scale growth and self-organized nanopatterning of 2D TMDs layer are shown, demonstrating superior photon harvesting properties and opening new perspectives in nanophotonics (2-6)In a first activity, we developed flat-optics schemes based on large-area few-layers MoS_2 forming periodic nanogratings. These 2D nanopatterned layers support Rayleigh Anomalies that promote strong in-plane light confinement and photon absorption enhancement, with superior photon harvesting performances in the ultra-thin layers. As a step forward, arbitrarily defined few-layer MoS_2 nanopaths

and nanocircuits have been achieved thanks to a new **additive** nanofabrication approach, based on a combination of thermal-Scanning Probe Lithography with physical deposition by ion beam sputtering, showing the potential of these building blocks in ultra-thin integrated electronic and photonic devices.

The combination of large-scale nanopatterning approaches with non-invasive 2D-TMD thermal lithography thus opens new promising possibilities for the integration of 2D TMDs layers in scalable photonics, electronics, and quantum technologies applications.

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Abstract 181 THU-AR-ISM-06-2 Invited Talk - Thursday 10:15 AM - Appaloosa (Hybrid)

Radiation defect dynamics in semiconductors

S. O. Kucheyev

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The formation of stable radiation damage in crystalline solids often proceeds via complex dynamic annealing processes, involving migration and interaction of ballistically-generated point defects. Here, I will review our recent studies of defect interaction dynamics in several semiconductors, including Si, Ge, SiC, GaAs, and BN. This work was performed under the auspices of the US DOE by LLNL under contract DE-AC52-07NA27344.

Abstract 278 THU-AR-ISM-06-3 Invited Talk - Thursday 10:15 AM - Appaloosa (Hybrid)

Uncovering Radiation Stability Regimes in Nanoengineered Tungsten Alloys through In Situ Ion Irradiation Experiments

Jason R. Trelewicz[1,2]

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Targeted alloying of grain boundaries has a profound impact on thermal stability, but for nanocrystalline alloys to be advanced as radiation resistant materials, an understanding of its influence on damage tolerance and stability is needed. In this presentation, results from in situ heavy ion irradiation of a titanium doped nanocrystalline tungsten alloy are discussed

with a focus on the coupling between defect accumulation and microstructural evolution. Relative to undoped tungsten, the alloy is shown to exhibit smaller defect loops and a delayed saturation dose, which is accompanied by a transient period of irradiation induced grain growth. Despite this modest coarsening, the grain structure remains decidedly nanocrystalline and plateaus at a much finer grain size than predicted for pure tungsten from a thermal spike grain growth model. Our results thus demonstrate that deliberate doping for enhanced thermal stability synergistically stabilizes the material against irradiation induced coarsening while limiting overall damage accumulation.

Abstract 133 THU-AR-ISM-06-4 Contributed Talk - Thursday 10:15 AM - Appaloosa (Hybrid)

Ion beam induced infrared color centers in silicon as quantum emitters and sensors of irradiation damage

Wei Liu[1], Qing Ji[1], Arun Persaud[1], Kaushalya Jhuria[1], Vsevolod Ivanov[1,2], Jacopo Simoni[2], Walid Redjem[3], Yertay Zhiyenbayev[3], Christos Papapanos[3], Boubacar Kante[3], Liang Z Tan[2], Javier Garcia Lopez[4], Thomas Schenkel[1]

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Infrared light-emitting defect centers in Si have revealed emerging applications as quantum emitters, optical access quantum memories and quantum sensing. The established silicon-based manufacturing platforms further leverage capabilities of on-chip integration for quantum information processing. Here, we characterized the optical properties of G centers created in silicon with as-received carbon under nanosecond-pulsed and continuous-wave (cw) 1 MeV proton irradiation. We observed that as the fluence increased from 10^9 cm^{-2} to 10^{13} cm^{-2}, the G center under cw irradiation preserves narrow linewidth < 0.08 nm (full width at half maximum of photoluminescence (PL) spectrum), which is one of important metrics towards single photon sources. Meanwhile, in the pulsed condition, the linewidth becomes significantly broadened from 0.08 nm to 0.13 nm, which indicates that the pulsed protons create a larger degree of atomic disorder around the G centers. However, the PL decay time of G centers decreases for both cw and pulsed irradiation as the proton fluence is increased, which indicates the two different irradiations introduce a similar amount of nonradiative defects. Note that the vacancy related nonradiative defect is a form of atomic disorder in Si. To reconcile the different linewidth broadening versus a similar amount of nonradiative defect between cw and pulsed irradiation at high fluence, we infer that the later introduces vacancy clusters causing a stronger degree of atomic disorder. In addition, we performed 70 keV Ar irradiation with 10^{12} cm^{-2} fluence on the same Si wafer, which generates damage events 3 orders of magnitude higher than 1 MeV protons with 10^{13} cm^{-2} fluence. We observe the formation of G centers with broader linewidth (0.16 nm) from Ar irradiation, which further indicates linewidth broadening due to vacancy clusters induced by dense damage cascades. In conclusion, our results present insight to the G color centers formation dynamics in Si under various ion beam irradiation conditions and as a sensitive probe for irradiation damage and atomic disorder.

Acknowledgment: this work at Berkeley Lab was supported by the Office of Science, Office of Fusion Energy Sciences, of the U.S. Department of Energy, under Contract No. DE-AC02-05CH11231.

Abstract 46 THU-AR-RE-05-1 Invited Talk - Thursday 10:15 AM - Pioneer IV

Investigating Radiation Effects in Oxides using State-of-the-Art Particle Accelerators

Maik Lang

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We describe in detail a methodology for comprehensively characterizing radiation effects in nuclear and other materials using large-scale particle accelerator facilities (1)Key to this approach are swift heavy ions with a penetration depth of ~100

μm, which is high enough to produce sufficient quantities of irradiated material for characterization using bulk techniques (2)Irradiation experiments are performed at the UNILAC accelerator at the GSI Helmholtz Center using Au ions of 2 GeV kinetic energy (Figure 1). The irradiated samples are complementarily characterized by means of advanced (accelerator-based) scattering techniques at the Advanced Photon Source (APS) and Spallation Neutron Source (SNS). High resolution diffraction, absorption, and total scattering experiments reveal ion-beam induced structural and chemical modifications, such as defect formation (**e.g.**, CeO_2), disordering (**e.g.**, $Ho_2Ti_{2-x}Zr_xO_7$), crystalline-to-crystalline phase transformations (**e.g.**, Gd_2O_3) and amorphization (**e.g.**, Dy_2TiO_5). Diffraction techniques give information on phase behaviour and disordering/amorphization of the average crystal structure (long-range), while pair distribution function (PDF) analysis from total scattering data provides detailed real-space information on the local defect structure. X-rays provide excellent sensitivity to high-**Z** elements, while neutrons scatter strongly from low-**Z** elements. The combination of short and long length scale characterization techniques with high sensitivity to both cations and anions is particularly important for characterizing radiation effects in oxide materials for nuclear application (**e.g.**, UO_2). Based on several examples, we demonstrate that accelerator-based characterization techniques yield fundamental insight into radiation effects in materials that are much more complex than previously thought [3-6].

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Abstract 33 THU-AR-RE-05-2 Invited Talk - Thursday 10:15 AM - Pioneer IV

Cryo-Ionoluminescence in Amorphous Silica - Kinetics of Self-Trapped Excitons and Extrinsic Centers

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Cryo-ionoluminescence studies of fused silica were performed at temperatures from 30-100 K using light and heavy ions (3 MeV H, 3.5 MeV He, 19 MeV Si, and 10 MeV Cl). The initial spectral evolution at low temperatures enables the deconvolution of heavily overlapping and asymmetric emission bands centered at 1.9 eV, 2.2 eV, and 2.7 eV. Based on their kinetic behavior with respect to temperature, electronic energy loss, and nuclear energy loss, the identity of those previously ambiguous emissions can now be associated with Non-Bridged Oxygen Hole Centers (NBOHCs, 1.9 eV), intrinsic recombination of Self-Trapped Excitons (STEs, 2.2 eV), and Oxygen Deficient Centers (ODCs, 2.7 eV). The initial light yield of the intrinsic STE emission reveals a complex process of STE formation, migration, and recombination. A parameter-free model was developed that quantitatively reproduces the experimentally observed light yield. The model describes a competition between non-radiative Auger recombination, STE formation and dissociation, and carrier hopping

with an activation energy of 0.12 eV. The generation of NBOHCs and ODCs follow different routes. Electronic excitation processes are mainly responsible for the generation of the NBOHCs, whereas the ODCs mostly result from ion-atom collisions. A detailed analysis has confirmed, through comparison of the results with SRIM simulations, that the intensity of the 2.7 eV emission is, indeed, well correlated to the predicted oxygen vacancy production rate and therefore attributed to the ODC.

Abstract 66 THU-AR-RE-05-3 Invited Talk - Thursday 10:15 AM - Pioneer IV

Response of defective $KTaO_3$ to inelastic interactions of ions

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Understanding the inelastic interactions of ions with defective $KTaO_3$ may provide nonequilibrium pathways to tune the functional properties of this perovskite. In this regard, defective $KTaO_3$ has been irradiated with several ion species (5 MeV C, 7 MeV Si, 12 MeV O and 18 MeV Si ions) over an extended selection of ion fluences at 300 K. By exploring these processes in $KTaO_3$, the experimental characterization and computer simulations show that, for a pre-damaged fractional disorder level of 0.3 and $S_e > 4.65$ keV/nm (7 MeV Si ions), the synergistic effect is active, which enables ion track creation under these conditions (1,2)In additions, we further reveal that the size of these latent ion tracks increases with Se and level of pre-existing damage (1)For $S_e < 3.03$ keV/nm (5 MeV C and 12 MeV O), minor increases in disorder are observed initially over a region of depth at an ion fluence of 10 ions/nm^2, which may be triggered by the dissolution of pre-existing interstitial or amorphous clusters; surprisingly, with further increase in ion fluence, a ionization-induced damage recovery processes is observed (2)These findings reveal a competitive two-stage phase transition process that leads to damage recovery process, not previously reported in $KTaO_3$.

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Abstract 109 THU-AR-RE-05-4 Contributed Talk - Thursday 10:15 AM - Pioneer IV

Near-surface disorder in 4H-SiC induced by MeV light ion irradiation

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Single-crystal silicon carbide (4H-SiC) was irradiated with 1570 keV hydrogen (H) ions and 4200 keV helium (He) ions in order to investigate the nature of the damage that might be induced by exposure to protons, fast neutrons, or alpha particles

in a nuclear reactor or waste storage environment. Raman spectroscopy and ion beam channeling were used to investigate the extent and nature of the disorder caused by light ion irradiation just under the surface of the material, rather than at the end of the ion beam range. The results suggests that the Monte Carlo simulation program SRIM correctly predicts the relative amount of ballistic displacement induced by H and He ions, as measured by the number of antisite defects and extinction of characteristic Raman features, with complete chemical disorder achieved at less than 0.10 displacements per atom (dpa). In contrast, ion beam channeling measurements indicated that full structural disorder (amorphization) required much higher levels of atomic displacement. In the case of H irradiation, the rate of disorder accumulation was consistent with the direct-impact / defect-stimulated (DI/DS) model found in other studies, with no evidence of temperature-induced defect recombination. In the case of He irradiation the overall amount of amorphization and loss of crystallinity was only 25% of that expected from the same low-temperature DI/DS model. These results are discussed in light of a possible ionization-induced recrystallization or defect recombination mechanism induced not directly by the He ion, but by ionization in the cascades of the highest energy recoil atoms.

Abstract 174 THU-PR-AMP-01-1 Invited Talk - Thursday 10:15 AM - Pioneer II

Experimental and computational studies of nano-structured gold as a radiosensitizer for proton and carbon ion radiation

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Nanostructured materials are widely being studied as radiosensitizers to increase the efficacy of radiation therapy in the treatment of cancer. While most studies have focused on sensitization for irradiation by photons, our recent studies include charged particle radiation, which is important as hadron therapy continues to expand. At East Carolina University, we are conducting experimental and computational studies of nanostructured gold as a radiosensitizer for charged particle radiation. Here we present recent results for enhanced cell killing for **in-vitro** irradiation by protons of malignant prostate and breast epithelial cells treated with gold nanoparticles in an energy range approaching the Bragg peak. The experiments were conducted in the ion beam facility at East Carolina University using the recently upgraded cell irradiation beamline.

In addition, we are expanding current Monte Carlo track structure simulation models to include swift-ion-induced secondary electron emission from gold. Furthermore, to explore differences between secondary electron production and transport in the bulk from nanostructured surfaces, we have measured doubly differential electron emission yields from gold foils and from gold nanostructures, including hydrated gold surfaces, induced by fast proton and carbon ion impact. These data suggest the importance of the surface structure on low-energy electron emission, which may affect radiation damage from secondary electrons in the cellular environment and influence cell killing.

Abstract 256 THU-PR-AMP-01-2 Invited Talk - Thursday 10:15 AM - Pioneer II

Doubly Differential Electron Yields from Proton and Carbon Ion Interactions with Gold Nanoparticles

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Radiosensitizing nanostructures enhance the local dose delivery system of radiation therapy in the treatment of cancer due to increased secondary electron emission. Doubly differential electron emission yields (1-100 eV) from near Bragg peak (1-6 MeV/amu) proton and carbon ion interactions with gold nanoparticle and hydrated gold nanoparticle solid-state targets have been measured using time-of-flight analysis in ultra-high vacuum. These measurements are compared to similar conditions for high-purity amorphous solid water and gold foil targets and may provide insight into more complex modeling of nanostructure environments.

Abstract 172 THU-PR-AMP-01-3 Contributed Talk - Thursday 10:15 AM - Pioneer II

Radiative double-electron capture (RDEC) by F^{9+} ions in collisions with single-layer graphene

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Radiative double-electron capture (RDEC) occurs when the capture of two electrons by a fully stripped ion isaccompanied by the simultaneous emission of a single photon. This process, fundamental in atomic collisions, is considered the inverse of double photoionization by a single photon. RDEC has been successfully studied with $F^{9,8+}$ ions on gas[1] and thin-foil[2] targets. Only recently has it been investigated for single-layer graphene[3].

This work was done at WMU with the 6-MV tandem van de Graaff accelerator. A graphene target (~0.35 nm thick) was mounted on a silicon nitride supporting grid (200 nm thick) consisting of ~6400 holes of 2 μm diameter on a 200 μm thick hexagonal silicon substrate with a 0.5 x 0.5 mm aperture. For single-layer graphene the foil thickness is close to that of the gas target and about a hundred times smaller than the thin-foil carbon used. A Si(Li) x-ray detector placed at 90° to the beam detected the emitted x rays in coincidence with magnetically separated outgoing charged particles counted with silicon surface-barrier detectors. The data were stored using event-mode collection so that the coincidences could be sorted either looking at the particles in coincidence with the x rays in the RDEC region or by looking at RDEC x rays in coincidence with the particles.

In preliminary work for RDEC with graphene, results for 2.11 MeV/u F^{9+} ions suggested cross sections approaching values found for thin-foil targets when the thickness of the graphene was about a hundred times smaller. For F^{9+} projectiles, a differential cross section value at 90° was found to be 1.3 b, corresponding to a total cross section (assuming isotropy) of 11 b. These values are more in line with the earlier values found for F^{9+} incident on gas targets, but larger by about a factor of 4, and are reasonable in view of the target thickness for the graphene compared to gas.

In the present work, the RDEC measurements have been repeated with single-layer graphene as well as a sample that had no graphene on it. X rays attributed to RDEC were seen for two separate graphene samples, while no RDEC x-rays were observed for the sample without graphene as expected. These measurements were just completed and analysis is underway, so the results will be reported later. Cross section values, which will be obtained from the data, will be compared with our previous gas target[1] and C-foil target[2] results.

Supported in part by NSF Grant No. 1707467

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Abstract 166 THU-PR-AMP-01-4 Contributed Talk - Thursday 10:15 AM - Pioneer II

Electron-ion recombination rate coefficients for plasmas modeling

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Reliable electron-ion recombination data are needed for plasmas modeling. Recombination processes include radiative recombination (RR), dielectronic recombination (DR), and three-body recombination. When a free electron is captured by an ion with simultaneous excitation of its core, a doubly-exited intermediate state may be formed. The doubly excited state relaxes either by autoionization or by photon emission. DR process takes place when the relaxation occurs to a bound state by photon emission. Discrepancies between theoretical and experimental DR rate coefficient measurements are observed at low energies. DR calculations at low temperatures are problematic and challenging since small uncertainties in the low-energy DR resonance positions can produce huge uncertainties in DR rate coefficients. DR rate coefficient results for different ions are calculated using state-of-the-art multi-configuration Breit-Pauli atomic structure AUTOSTRUCTURE collisional package within the generalized collisional-radiative framework. DR cross sections for these ions are convoluted with the experimental electron-cooler temperatures to produce DR rate coefficients. Good agreements are found between these rate coefficients and the experimental measurements performed at CRYRING heavy-ion storage ring for both ions.

Abstract 58 Poster - Poster Sessions

Detection of shielded special nuclear materials and other contraband by using portable, high-flux DD and DT neutron generators

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There has been a greatly increasing demand for rapid and reliable detection of shielded and unshielded special nuclear materials (SNM) and other contraband (i.e., explosives, chemical warfare agents, and drugs) in conveyances of various sizes from the U.S. Department of Homeland Security and counterpart agency in other countries. Active interrogation using either neutrons or photons has been demonstrated to be an effective approach to addressing this demand. Considering the fact that active photon interrogation systems typically have a rather high cost and they cannot be deployed easily due to the complexities of these systems, active interrogation using neutrons produced from portable, high flux, and affordable sealed-tube DD and DT neutron generators is being investigated. The signatures that are being explored to detect the presence of SNMs and other contraband based on these neutron generators are the prompt neutrons emitted during the fission process and the characteristic gamma-rays produced from fast neutron inelastic scattering and thermal neutron capture reactions, respectively. A few key challenges facing the aforementioned active neutron interrogation method have been identified as follows: a) the active background is very complex, and it is likely to be time dependent; b) neutron flux varies significantly from pulse to pulse and the structure of the pulses is not ideal; c) the signal-to-noise ratio is unacceptably low when the contraband is heavily shielded in large-sized conveyances, such as sea cargo; d) the neutron flux of the pulsed DD neutron generators that are currently available is much lower than the desired flux. Novel radiation detection technologies and statistical signal processing algorithms are being developed to address these challenges.

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Poster - Poster Sessions

Light-Ion Production of Gold Radioisotopes from Natural Platinum Targets

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Gold radioisotope production cross sections were investigated in support of nuclear data. The irradiations were performed at Lawrence Livermore National Laboratory's (LLNL) Center for Accelerator Mass Spectrometry (CAMS) facility. Irradiations were done using the 10 MV FN tandem accelerator and the NEC Toroidal Volume Ion Source (TORVIS). Gold radionuclides were produced from both proton and deuteron beams with natural platinum targets. Cross sections at near-barrier energies have been experimentally determined for proton beams using the stacked target method. This includes the first such analysis of ^{190}Au. Additionally, isotope-specific reaction cross sections are included using the natural platinum abundance values. All cross sections are compared to TENDL-2019. Deuteron yields are analyzed for the sole motivation to extend the suite of radiogold nuclides to include ^{199}Au.

Abstract 216

Poster - Poster Sessions

3 MeV Pelletron Facility at Sandia National Laboratories

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An overview of the 3MeV Pelletron Facility at Sandia National Laboratories Ion Beam Lab.

Abstract 260

Poster - Poster Sessions

Innovative Magnetron Power Sources for Superconducting Accelerators

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A magnetron suitable for 1497 MHz klystron replacements at Jefferson Lab will be constructed and tested with our novel patented subcritical voltage operation methods to drive an SRF cavity. The critical areas of magnetron manufacturing and design affecting life-cycle costs that will be modeled for improvement include: Qext, filaments, magnetic field, vane design, and novel control of outgassing. The most immediate benefit of this project is to make SRF accelerator projects more affordable for NP and other users of SRF Linacs. One of the most attractive commercial applications for SRF accelerators is to drive subcritical nuclear reactors to burn Light Water Reactor Spent Nuclear Fuel (LWR SNF). A 1 GeV proton beam hitting an internal uranium spallation neutron target can produce over 30 neutrons for each incident proton to allow the reactor to operate far below criticality to generate electricity or process heat while reducing high-level waste disposal costs. This commercial application has the additional attribute of addressing climate change.

Abstract 47

Poster - Poster Sessions

Optical properties of SiGe nanocrystals in SiO_2 produced by ion implantation

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Silicon is the most used material in the electronic industry, with applications in many areas. Although silicon has excellent electronic properties, it lacks light emission due to its indirect bandgap. Nonetheless, light emission in silicon nanocrystals has been reported due to the quantum confinement effect. This fact unlocked the potential for silicon-based optoelectronic devices, and many studies have investigated quantum confinement in Si quantum dots (QDs). In this project, we explore the possibility of adding germanium to create silicon-germanium (SiGe) nanocrystals. The relative concentration of Ge has a direct influence on the optical properties since the bandgap depends on it. Besides being a widely used technique in the microelectronics industry, ion implantation can be used to make compounds beyond the chemical solubility limit, and allows the study of a range of concentrations of Si and Ge. By changing the Ge content, different wavelengths of emitted light can be achieved and adjusted according to the required application. Si^+ at 40 keV was implanted into a 1 μm thermally grown SiO_2 film on a Si (001) substrate to achieve a peak concentration of 17.5 at. % in relation to the matrix. The chosen energy placed the implanted peak 50 nm below the surface. Samples were subsequently implanted with 55 keV Ge^+ with 0.5, 1.0, 2.0, 4.0, and 7.5 peak at. %, and thermally annealed to promote clusters growth and crystallization. The Ge implantation energy was calculated to put the Ge ion range at the same position as the Si ion range. For a second set of samples, Ge^+ implantation was done after 1100°C annealing, necessary for Si QDs growth. We present the optical properties of these SiGe QD ensembles, studied with photoluminescence in the visible and near-infrared. Both sets of samples present emission around 780 nm and 1050 nm. It was observed that PL intensity decreases in both sets of samples with increasing Ge content, and the sample with no annealing between implants exhibits more intense PL. A blue shift in the 1050 nm emission peak provides evidence of Ge incorporation in Si QDs in both sets of samples.

Abstract 71 Poster - Poster Sessions

The Impact of SHI Irradiation on the Low-Temperature Dielectric Phase Transition in $K_2Bi_4Ti_4WO_{18}$

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The Polycrystalline $K_2Bi_4Ti_4WO_{18}$ was synthesized with a solid state reaction technique and the impact of Swift Heavy Ion (SHI) irradiation on the surface and dielectric properties were studied in detail. The Le-Bail approach confirmed the Phase formation and space group symmetry (B2cb). The irradiation of 150 MeV Ni^{+11} ions enhances the surface roughness and penetrates the surface up to 20μm as reflected in the AFM imaging. The impact of the modified surface also reflects in the dielectric properties with a significant change in the dielectric phase. In addition, the study suggests that the deposition of highly energetic ions on the surface creates a new energy barrier and enhances the dipolar activation energy by 109% as presented in impedance and modulus studies. The AC conductivity enhanced drastically after irradiation at approximately 1300% and deviated by jonscher's power law, correlated with the change in dielectric constant and modulus behavior. The appearance of the helical Nyquist plot after irradiation was explained with an inductive effect as a result of metal ion deposition. The observed change in the dielectric phenomenon was attributed to the surface modification because of irradiation.

Abstract 178 Poster - Poster Sessions

Time-Resolved Digital Data Analysis for Neutron Active Interrogation

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Detecting shielded contraband material, including special nuclear material (SNM), drugs, and explosives is a persistent technical challenge. The signatures from contraband materials are often weak compared to the interrogating source, requiring the use of long measurement times and high radiation doses from the interrogating source. We are exploring new

digital pulse processing techniques for active neutron interrogation to enhance the detection of SNM and contraband that may be concealed in cargo containers, with a focus on prompt gamma-ray signatures for drug and explosive detection and fast neutron detection for SNM. We apply these algorithms to traditional and modern inorganic scintillators and use pulse shape and fast timing analysis to improve the efficiency of the active interrogation systems. In this work, these measurements are combined with high-fidelity simulations to characterize the performance of neutron generators and the necessary properties of radiation detectors. The new detection systems make use of digital data acquisition from inorganic and organic scintillators along with the time structure of the DD and DT interrogation sources to improve the signal-to-noise ratio of the measurements.

We characterized the fast neutron time profile of the Thermo Scientific P211 DT and MP 320 DD neutron generators using organic scintillators and a gamma-blind He-4 recoil-based fast neutron detector. The initial 14.1-MeV fast neutron signal is distinguished from scattered neutrons and induced gamma rays corresponding to room return via pulse shape discrimination and setting a recoil-based neutron energy threshold. This fast neutron time profile provides insight into appropriate time gating of gamma-ray and neutron signals to improve the signal-to-background ratio for contraband detection based on the anticipated timing of the signal of interest. For example, selection of gamma ray events within an initial spike of 14.1 MeV neutrons within the time profile rejects a large portion of background gammas associated with thermal neutron capture as this background is delayed by the thermalization time. The associated prompt gamma-ray time profile is additionally measured using a range of inorganic scintillators, including fast inorganic scintillators such as $LaBr_3$. Initial spectral results are shown of active interrogation measurements performed with various contraband simulants. Based on these results, combined spectro-temporal analysis is being developed to allow for the detection of shielded contraband with greater sensitivity.

Abstract 258 Poster - Poster Sessions

Capability of 6MV Tandem Accelerator Facility at Sandia National Laboratories

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Abstract 193 Poster - Poster Sessions

Exploring new methods to monitor proton beam damage for sequential elemental and molecular imaging on a single tissue section

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Monitoring the effects of proton beam damage in biological materials is of interest to enable the integration of proton microprobe elemental mapping with molecular imaging modalities and further our knowledge of chemical changes caused to tissues during proton beam cancer therapy. In a recent publication, de Jesus **et al.** reports on performing sequential mass spectrometry imaging (MSI) and ion beam analysis (IBA) on the same tissue sample. Data indicated that irradiating the sample with a proton beam caused measurable changes in the lipid profiles detected between irradiated and non-irradiated regions. Here we describe a novel approach to characterise proton beam damage to lipids in biological tissues, based on mass spectrometry imaging, specifically desorption electrospray ionisation (DESI). The developed methodology is applied to characterise changes to lipid profiles irradiated under different conditions: ambient pressure, high vacuum, beam scan speed and pattern and application of a matrix to the sample. This work shows that performing proton beam irradiation at ambient pressure, as well as the application of an organic matrix prior to irradiation can reduce changes in lipid profiles in tissues.

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Poster - Poster Sessions

in-situ Defect Characterization of Ion Irradiated Materials with Positrons

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Positron Annihilation Spectroscopy (PAS) is a technique that non-destructively probes atomic-scale vacancies and voids. As part of the FUTURE EFRC, PAS will play a vital role in studying the evolution of defects in materials under irradiation, stress, and corrosion. We present the development of an **in-situ** pulsed variable energy positron beamline at LANL's IBML facility. The positron beam is coupled to a dual-beam irradiation chamber that uses a heavy ion beam from a 3 MV tandem accelerator for displacement damage production and a He/H ion beam from a 200kV ion implanter for emulating gas production by fast neutrons in advanced nuclear systems. The preliminary results of single crystalline Fe samples irradiated with 3 MeV Fe ions with 15 keV positrons are reported.

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Poster - Poster Sessions

μ-PIXE Analysis of Ceramics Recovered during the Summer 2022 Excavations at the Spiro Mounds Archaeological Site, Le Flore County, Oklahoma

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Herein μ-PIXE analyses of ceramics recovered from the Spiro Mounds archaeological site are reported. During the summer of 2022, excavations took place at Spiro Mounds, a Mississippian period archaeological site that was inhabited from about 900 AD-1450 AD. Ceramic artifacts were recovered during these excavations, and small white inclusions of unknown composition were observed in these ceramic materials. Because these unknown inclusions were used as a temper for these ceramics, it was important to identify the composition of this material in order to correctly classify these ceramics. μ-PIXE was used to characterize the temper material, which allowed the ceramics to be properly classified before being stored in the Sam Noble Oklahoma Museum of Natural History.

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Poster - Poster Sessions

Comparison of PIXE and XRF Results on Ancient Egyptian Bronze Artifacts

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The Louisiana Accelerator Center (LAC) at the University of Louisiana at Lafayette recently studied a set of ancient Egyptian artifacts (712-332 BC). The objects are from the collections of Museo Egizio, the oldest museum in the world dedicated to Egyptian antiquities. The New Orleans Museum of Art hosted the Queen Nefertari's Egypt exhibition this year, organized in collaboration with StArt and Museo Egizio. Two bronze objects from the exhibition, the handle and the upper

part of a sistrum (sacred musical instrument of ancient Egypt), were brought to LAC for investigations. The artifacts exhibited various degrees of patina; no surface alterations were permitted.

LAC operates a National Electrostatics Corporation 1.7 MV 5SDH-2 tandem Pelletron® accelerator as a source of ions for a micro-beamline end station. A square profile (7 x 7 μm) proton beam of 2 MeV was used to analyze the Egyptian bronze artifacts using particle induced x-ray emission (PIXE). A ThermoScientific Niton XL3t Ultra hand-held x-ray fluorescence (XRF) gun was used in parallel, to compare the samples' elemental composition determined through XRF and PIXE. This device was operated at 40 μA, with a range of 0-50 keV and a penetration depth of several millimeters.

The PIXE analysis was limited to one spot on each artifact due to geometrical and size constraints when mounting the pieces into the target chamber. These spots were also targeted in the XRF analysis. Flexibility in operating the XRF gun allowed for data acquisition on additional spots for each sample, comparing heavily and minimally corroded areas. Five 20-second trials were conducted per spot while the device was held directly over the sample, to minimize target-to-analyzer distance. Comparisons between results obtained through XRF and PIXE are particularly important to conservators. PIXE has the ability to determine sample compositions to the part per million (ppm) level. XRF is easily implemented, portable, and can be used on delicate samples, all at a possible loss of accuracy. Comparing results provides insight into the validity of the more-available XRF method.

Preliminary analysis shows similar relative concentrations between the two methods for the major bronze constituents (copper, tin, and lead) for each object tested. The heaviest element present, lead, has the best agreement in concentration between the two methods. Differences in results can be attributed to varying penetration depths or insufficient XRF observation times. This experiment provides a useful introduction into comparing microbeam PIXE analysis with XRF measurements. In future work, an increased exposure time for XRF data acquisition should be paired with a minimal detector-to-sample distance. This experience helps to better plan a refined experiment on soil samples (underway), as field measurements of soil contamination are generally done with XRF instruments. In a similar fashion to the current study of antiquities, a validation of XRF measurements can be investigated through a parallel PIXE analysis.

Abstract 244 Poster - Poster Sessions

Time-resolved neutron reflectometry study of Li-mediated electrochemical nitrogen reduction

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Li-mediated electrochemical reduction of nitrogen to NH_3 has been identified as an alternative to the resource-demanding Haber-Bosch ammonia process. Through this Li-mediated process, an initial electrodeposition of Li is followed by a reaction to form Li_3N and subsequent ethanolysis of Li_3N to form NH_3. We report on the study of the initial phase of this process with time-resolved neutron reflectometry at the Liquids Reflectometer at SNS. We studied Li electrodeposition on a molybdenum thin film in contact with deuterated THF with 0.2 M $LiClO_4$ and 1 v% EtOH at a current density of -0.1 mA/cm^2. The neutron reflectometry data acquired during the first five minutes of Li plating was sliced in 60-second intervals in a wide enough Q range ($0.017 < Q < 0.05$ 1/Å) to allow time-resolved modeling of the plating process. The observed Li layer and the absence of a clear solid-electrolyte interphase layer in this time frame is of particular interest since cycling on the time scale of minutes has been identified as a way to enhance selectivity towards NH_3.

Abstract 243 Poster - Poster Sessions

The Liquids Reflectometer at the Spallation Neutron Source

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The Spallation Neutron Source (SNS) is an accelerator-based system that delivers microsecond pulses of protons to a steel target containing flowing liquid mercury to produce time-of-flight neutrons for use in neutron scattering studies. Neutrons produced in this way are then directed toward state-of-the-art instruments so researchers across disciplines, such as physics, chemistry, biology, and materials science, can investigate structure and dynamics in materials. The SNS is the most powerful source of its kind in the world and is located at Oak Ridge National laboratory. The Liquids Reflectometer (LR) is an instrument located on the SNS that is designed to study interfacial phenomena at air/liquid, air/solid and liquid/solid interfaces. The LR is an ideal tool to probe surface and interfacial structures of thin films on length scales of 0.5nm to 350nm. The LR is useful for a wide range of science topics. Researchers use it to study biomaterials, polymers, electrochemistry, corrosion, and chemistry involving thin layers of surfactants or other materials on the surfaces of liquids, such as cell-membrane analogs. These systems provide a flexible platform to study structure-property relationships at the boundary between hard and soft matter, with applications in biomimetics, bio-sensing, bio-compatible films, hydrogen storage, batteries, fuel cells, and polymers. A variety of sample environments are supported, including an 18-slot robotic sample exchanger, temperature-controlled liquid/solid and potentiostatically controlled electrochemical cells, vacuum and gas-handling chambers, a high electric field chamber, and a Langmuir trough.

Abstract 10 Poster - Poster Sessions

Band gap modification of CVD grown few-layer MoS2 under Swift heavy ion irradiation

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The suitability of homogenous, transferable, highly crystalline few-layer Molybdenum disulfide (MoS_2) for usage in optoelectronic device applications may be impacted by the difficulty of its manufacture in large quantities. Traditional chemical vapor deposition (CVD) techniques have challenges since they usually rely on high-melting-point precursors like MoO_3 and Mo powder. This article offers a simple CVD technique that employs alkali halide (NaCl) to create high-quality few-layer MoS_2, confirmed by Raman spectroscopy. By using this technique, the evaporation temperature of the CVD process that produces MoS_2 is reduced from 850℃ to 650℃. The peak difference between the characteristic Raman peaks of MoS_2 A_{1g} to E^1_{2g} lies around ~ 24.5 cm^{-1} which corresponds to less than 5 few layers of MoS_2 on the substrate, which is also confirmed by the AFM sectional height analysis. Since then, band gap tuning is preferred for prospective use in a variety of industries, including optoelectronics and electronics. In this work, SHI irradiation at various ion energies was used to modify the considerable band gap in few-layer MoS_2. We have chosen the ion's energy in such a way that three different energies lie within the symmetry point of Bragg's peak in ion energy loss per unit length curve. The utilised ion energies are 60 MeV, 100 MeV, and 150 MeV Ni-ion at 10×10^{11} ions/cm^2. From the UV-Vis spectroscopy of the SHI-irradiated samples, the wavelength sorting of the absorption peak under the ion fluence of different energies indicates the band gap shifting of the nanometer orders. Since the absorption peaks for 60 MeV and 150 MeV are unshifted, it indicates the ion energy loss per nm for two different energies have the same energy loss per nm (11.0 keV/nm), showing the same effect in the band gap modification. However, the 100 MeV Ni-ions having different ion energy loss per nm (11.3 keV/nm) show considerable absorption peak shifting (from 680 nm to 674 nm for A-peak and 630 nm to 624 nm for B-peak) indicates the band gap modification. This study will be useful for the creation of extremely effective 2D-MoS_2 solar cells and photoreactors.

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Anomalous phase transformation in swift heavy ion-irradiated δ-$Sc_4Hf_3O_{12}$

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Oxide ceramics are the candidate materials for encapsulating minor actinides. For this application, knowledge on structural changes and stability under radiation environments is required. Oxygen-deficient fluorite structural derivatives ($M_{1-x}M'_xO_{2-x}$, where M and M' are aliovalent metal cations and O is the anion), which contain oxygen vacancies to provide a charge compensation mechanism that satisfies the electroneutrality, have attracted attention for their radiation effects, because oxide ceramics with a fluorite type structure are known to exhibit excellent radiation resistance. In the present study, we examined the structural changes of swift heavy ion irradiated δ-$Sc_4Hf_3O_{12}$. Polycrystalline sintered pellets of δ-$Sc_4Hf_3O_{12}$ were irradiated at room temperature with 92 MeV xenon (Xe^{26+}) ions to fluences ranging from 3×10^{12} to 1×10^{14} /cm^2. The specimens were characterized by grazing incidence x-ray diffraction, transmission electron microscopy, and scanning transmission electron microscopy. We found an ordered δ-phase transforms to a disordered fluorite phase with increasing ion fluence. In addition, a new ordered phase with a short-range structure different from the δ-type was found from the surface to a depth of ~4.5 μm in the specimen irradiated to a fluence of $1 \times 10^{14}/cm^2$. Electron diffraction patterns were identical with those of the bixbyite structure. This means the following structural changes were induced by irradiation: δ-type [space group: R-**3** (No. 148)] → fluorite [Fm-**3**m (No. 225)] → bixbyite (Ia-**3** (No. 206))This structural change is anomalous, because it is the opposite process of the usual irradiation-induced structural change, the order-to-disorder phase transformation [1].

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Abstract 171

Poster - Poster Sessions

Investigation of the stopping power of energetic ions in liquid water

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The need for precise measurements of the stopping power of energetic protons in liquid water is paramount in the prediction of range and linear energy transfer in biological targets, including oncology patients undergoing proton therapy. Today, there is a clear discrepancy in the stopping power of protons in liquid water at and around the Bragg peak. The currently accepted values from the International Commission on Radiation Units and Measurements report number 49 cites values that can be inaccurate up to 20% around this region (1)Since the report's publication in 1994, there have been 3 experiments done to validify these numbers, two of which are under scrutiny. The purpose of this research project is to provide accurate experimental data on the stopping power of protons in liquid water, by means of an apparatus that can effectively hold a liquid in vacuum, and maintaining a uniform target thickness for the water. The apparatus proposed is an extension of a previous experiment's apparatus used to determine the stopping power of protons in liquid water [2], where a set of thin mylar windows were used to trap liquid water at varying effective thicknesses. That experiment was used to determine the stopping power for proton energies down to 4.2 MeV. To determine stopping power at lower energies, a modified apparatus needs to be built. The proposed apparatus, a liquid target holder comprising 7 layers is proposed, containing 4 silicon nitride windows with thickness of 200-nm, holding intermediate volumes of helium symmetrically about a water target of varying thickness will allow for accurate measurements of stopping power at energies significantly lower than 4.2 MeV.

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Abstract 81

Poster - Poster Sessions

Improvement of light element analysis by external proton beam

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We present new developments for ion beam analysis (IBA) using an external proton beam with an energy range of 2.0-2.5 MeV for simultaneous NRA, RBS, PIXE and C-ERDA measurements [1] The primary objective is the detection of light elements, such as hydrogen and lithium in free standing foils or thin films. We will show that the concentrations of light elements (H, Li, N, C, O, F) of materials can be determined outside of vacuum chambers which is essential for porous or humid samples. Furthermore, the destructive influence of the proton beam to the samples during the measurement is shown. As a further upgrade, we are working on an extension that allows rotation of the sample and thus counteracts unwanted effects such as channeling. This provides the possibility to compare the data with simulations, which will be done, with the new SDTrimSp/ImintDyn [2] software. With present results for the detection limit for hydrogen, lithium and flourine. The setup for Li detection will be further improved by upgrading the detectors for the U+2077 Li(p,U+03B1) U+2074 He reaction.

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Abstract 91

Poster - Poster Sessions

Simulation of MeV ion scattering including coincidence techniques for light ion depth profiling

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Monte-Carlo based binary collision approximation (BCA) simulations provide a fast and versatile simulation tool for low and medium energy ion-solid interactions. However, simulation of MeV ion scattering with small scattering cross sections is very time-consuming, except one introduces dedicated approximations and optimizations. For example, the code POTKU is optimized for real time simulation of ERDA spectra and CORTEO was optimized for various ion beam analysis problems including simulation of H-H coincidence scattering spectra.

We have developed the software IMINTDYN based on the SDTrimSP code as a versatile Monte Carlo code, which can be applied from ultra-low energy ion-solid interaction, to medium energy sputter erosion simulations up to MeV ion beam analysis simulations. For MeV ion scattering, the code uses features such as (i) flexible free path lengths in contrast to monolayer collision steps, (ii) enforced scattering options to enhance large angle scattering events, (iii) use of non-Rutherford cross section data similar to the analytical SIMNRA code, (iv) enhanced book keeping to allow scattering-recoil coincidence tracking. IMINTDYN can handle complex multi-element target structures as well as energy and angular distributions of incident ions.

We will present simulations of light ion coincidence spectroscopy scattering for H and Li depth profiling, but also simulations of Rutherford backscattering spectra and non-Rutherford scattering of MeV H ions. We will show that IMINTDYN complements the fast simulations provided by POTKU CORTEO or SIMNRA with additional detailed information on dual and multiple scattering and coincidence tracking.

Hydrogen detection using low and medium energy ions

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Low and medium energy ion scattering (LEIS and MEIS) are a powerful tool for depth profiling, capable of providing quantitative information on the structure and composition of shallow layers with sub-nm depth resolution near the surface (1, 2)These methods are applicable mostly for impurities with atomic number Z > 6 on light substrates, yet they lack sensitivity to light elements (H, D, He and B). Thermally driven transport and exchange of hydrogen isotopes in silicon-based metal-oxide-semiconductor (MOS) and other device-related structures is important for device performance and other fundamental studies. The motivation for this work was twofold: (i) importance of light elements quantification to obtain accurate stoichiometry, and (ii) general importance of hydrogen in semiconductor devices (for instance, giant hydrogen isotopic effect on hot-electron degradation mechanism).

There were several adaptations of MEIS in the past three decades to perform elastic recoil detection analysis (ERDA) using electrostatic energy analyzer (ESA) or time-of-flight (TOF) detection system in medium energy range (10-500keV). Copel **et al.** successfully demonstrated detection of hydrogen and boron using time-of-flight approach, with depth resolution of ~10Å (3)Nishimura **et al** [2] utilized a modified version of ESA with a wide interelectrode distance of 18 mm, covering a broad energy range $\mathbf{W}=0.1\mathbf{E_0}$, where $\mathbf{E_0}$ is the energy of ions detected along the central curvature of the ESA. Both H^+ and H^- detection was demonstrated, with sensitivity of 0.1ML. More recently, HoleňÁk **et al**. has shown possibility to detect hydrogen using ^{22}Ne and ^{40}Ar pulsed beams as projectile with TOF detector for samples in transmission geometry(4)For a large solid angles of the detector (0.13 sr), a high-depth resolution below 60 Å and sensitivity below 10^{14} atoms/cm^2 was achieved. Our implementation of medium energy (ME-ERDA) is based on using ~300-500keV N^+ or Si^+ ions as projectiles and detecting negative hydrogen (H^-) recoils using standard ESA detector (5)We applied this technique to the analysis of H-terminated Si (001), self-assembled monolayers, and 2-5 nm thick HfO_2 and $HfSiO_x$ films grown by atomic layer deposition on Si(001).

In order to determine the absolute quantity of H on Si by this approach, the charge fraction of H-, (which is dependent on the energy) must be estimated in advance. Quantitative analysis of hydrogen content in these thin films is complicated by the presence of residual hydrogenated species after expose to air and in vacuum system, giving rise to so-called hydrogen surface peak. Comparison between ME-ERDA, ERDA and SIMS results will be discussed, as well as the limitations of such analyses.

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Abstract 155 Poster - Poster Sessions

Ion Beam Analysis of a Cerium(III) Tris[bis(trimethylsilyl)amido] Phosphine Oxide Crystal

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Herein ion beam analysis of a cerium(III) tris[bis(trimethylsilyl)amido] phosphine oxide crystal, $Ce[N(SiMe_3)_2]_3[OPPh_3]$, is reported. Four-coordinate complexes of the lanthanides and actinides are extremely rare, and the synthesis and characterzation of $Ce[N(SiMe_3)_2]_3[OPPh_3]$ is a valuable contribution to **f**-element coordination chemistry. The $\mathbf{C_3}$ symmetric four-coordinate tris[bis(trimethylsilyl)amido] triphenylphosphine oxide framework has been reported for lanthanum, samarium, europium, erbium, lutetium, yttrium, and uranium. These axially symmetric four-coordinate silyl-amide phosphine oxide complexes are suitable models for studying the relative differences in lanthanide/actinide metal-ligand covalency using ^{31}P-NMR spectroscopy and X-ray emission spectroscopy. Expanding this structural framework to other lanthanide and actinide metals, and fully characterizing a series of isostructural complexes featuring various organic substituents on the phosphine oxide ligand (beyond triphenylphosphine oxide), would provide considerable insight concerning phosphine oxide bonding interactions with **f**-block metals.

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Designing Accelerator-Driven Experiments For

Accelerator-Driven Reactors

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Muons, Inc., with its collaborators, to the best of our knowledge is the only one of the several reactor concept companies in the US that is concentrating on an accelerator-driven subcritical high-power reactor design. The major objection to such systems has been that short interruptions of beam of even a few seconds would turn off fission power long enough to induce temperature-gradient shocks and subsequent fatigue of solid fuel elements. Mu*STAR solves this problem by using a molten-salt fuel. Mu*STAR is a reactor design that not only includes a particle accelerator as an integral part, but has several innovative features that make it a compelling solution to many problems. We note that the ADSR concepts being pursued by the Chinese Academy of Science (ADANES) and the Belgians (MYRRHA) are based on traditional solid fuel elements and require exceptional stability from their accelerator.

Abstract 167 Poster - Poster Sessions

Accelerator-Based Fusion Fuel Options for Using an Artificially Structured Boundary

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The accelerator-based fusion approach to energy production involves directing an ion beam at a target, such that fusion reactions occur between beam ions and target ions. Suppose that a proton beam is directed at a solid target made of boron-11. The protons would initially lose energy at a rate faster than the rate at which energy is produced by fusion reactions between protons and boron-11 nuclei. However, suppose further that an artificially structured boundary surrounds the

boron and produces a short-range field, such that electrons remain confined within a volume that is separated from external material structures.* That is, free electrons produced by ionization that travel to leave the target region are reflected by the short-range field and remain confined. The short-range field would not prevent boron-11 ions from leaving the target region. However, because the electrons are confined, the target region becomes negatively charged, thereby inhibiting further ion losses. The energy transferred from the proton beam to the boron-11 target goes predominantly toward heating electrons until the electrons form a plasma and reach a sufficiently high temperature. Also, the beam is considered to pass through a sequence of targets, with the beam reaccelerated and refocussed between targets. In the work reported, the ratio of the rate at which energy is produced by fusion reactions to the rate at which beam ions lose energy is found for a variety of possible fusion fuels (i.e., beam and target reactants) as a function of target electron temperature.

*An experiment that demonstrates the use of an artificially structured boundary for space-charge based ion confinement has recently been reported: A. S. Kiester, C. A. Ordonez, and D. L. Weathers, IEEE Transactions on Plasma Science 50 (2022) 210.

Abstract 138 Poster - Poster Sessions

Accelerator-Based Fusion With an Artificially Structured Boundary that Produces a Purely Magnetic Periodic Field

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Magnetic plasma expulsion is the process where a magnetic field is generated in order to prevent plasma from entering a desired region. In this report, magnetic plasma expulsion will be studied in combination with an artificially structured boundary which produces a spatially periodic magnetic field. The magnetic field associated with the artificially structured boundary is constructed from a sequence of parallel, current-carrying wires, and is capable of confining plasma within a specific region. Such a field requires many magnetic coils to be embedded within the plasma, and material structures may be necessary to keep the magnetic coils in place. In order to prevent plasma loss at the site of these material structures, a magnetic plasma expulsion field will be used to guide paticles away from the plasma-immersed structures. A series of classical trajectory Monte Carlo simulations will be conducted in order to evaluate the trajectory of plasma particles that are incident on the expulsion field. The results show that the magnetic plasma expulsion field can reflect particles away from material structures and back into the region of confined plasma.

Abstract 103 Poster - Poster Sessions

X-ray Spot Size Improvements and Challenges in the 7 MeV S-Band LINAC for NDT

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The X-ray spot sizes on the order of 1 mm FWHM or less (submillimeter) from high energy industrial accelerators are attractive in a range of Non-Destructive Testing (NDT) industries. However, the current limitations in technology and cost requirements limit spot size to an order of 2 mm. The 7 MeV energy regulated accelerator designed, built, and tested by Varex Imaging, previously reported at IPAC 2021, aims to overcome these difficulties, by providing high dose rate, a broad energy range, and a small beam spot. High power testing has demonstrated maximum dose rate of 1300 R/min at 1 m from a target and electron beam energy range from 4 to 8 MeV with maximum yield at 8 MeV and optional broader 3 to 8 MeV range with highest performance at 7 MeV. This paper discusses beam spot reduction challenges and current work being done to improve the accelerator beam centerline (ABC).

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Poster - Poster Sessions

Accelerator-Based Fusion with Reduced Electronic Stopping Made Possible by an Artificially Structured Boundary

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An overview is given of the issues and prospects for a concept referred to as accelerator-based fusion. Accelerator-based fusion is an approach for generating fusion energy by injecting a beam of accelerated ions into a target. While it is readily possible to accelerate ions to sufficient energies for energy-producing fusion reactions to occur within a target, it remains to be seen if the amount of energy produced by fusion reactions can be larger than the amount of energy required to accelerate the beam. Beam ions slow down within a neutral target as a result of electronic stopping and nuclear stopping. For a tritium beam and deuterium target, the amount of energy produced by fusion reactions is theoretically predicted to be larger than the amount of energy required to accelerate the beam, provided that the electronic stopping power is sufficiently small. There exist a number of possibilities for the electronic stopping power to be reduced. One possibility is for the target to be enclosed within an artificially structured boundary that produces a short-range field along the periphery of the target.* The applied field would serve to reflect incident target electrons, thereby confining electrons inside a target volume and away from external material structures. As a result of being confined, the target electrons would heat up to plasma temperatures where electronic stopping is significantly reduced. Alternatively, the temperature of the target electron plasma could be increased prior to the start of beam injection. The space charge of the target electron plasma would provide electrostatic confinement for target ions. The configuration envisioned would have an ion beam that passes through a number of targets in succession (e.g., along a storage ring). Between targets, the ion beam would be focussed and accelerated back to optimal injection conditions.

*An experiment that demonstrates the use of an artificially structured boundary for space-charge based ion confinement has recently been reported: A. S. Kiester, C. A. Ordonez, and D. L. Weathers, IEEE Transactions on Plasma Science 50 (2022) 210.

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Abstract 131

Poster - Poster Sessions

Simulation and Measurements for the 11B(p,α)2α Reaction Using a Multi-Detector Setup

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Measurement of nuclear reaction rates have important application in both modeling astrophysical environments and radiation treatment. At low proton energies the 11B(p,α)2α reaction produces three alpha particles through two reaction channels. Unfortunately, there is an overlap in energies between α-particles from differing reaction channels. Previous publications separated these α-particles using a graphical convention. These cross-section data have errors up to 30% and inconsistencies up to 50%.

We are designing and building a multi-detector setup with eight detectors, to more accurately measure the reaction's cross section. The eight detectors are placed in a cube-corner-arrangement. Software was also written to determine the energy output of boron nanoparticles to determine the optimum energy output for tumor treatment.

Using the conservation of linear momentum and the conservation of mass-energy the angles and energies of each alpha particle group can be estimated. Recording the alpha particles in coincidence with the multi-detector setup assists in separating the individual alpha spectra. The detector signals are processed with a digital data acquisition system that records energy, time and also the detector identification number. We present the current status and discuss the future developments for the apparatus and experiment.

Abstract 110 Poster - Poster Sessions

XPS measurements of organic molecule degradation after exposure to MeV ion irradiation

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To understand radiation-induced material degradation in polymers and some ceramics, as well as health effects in biological systems, it is important to assess all possible reaction mechanisms. Although many aspects of ionization damage are well-understood, the complex nature of the interactions between radiation fields and particular nuclei could add complexity to the actual damage done in realistic environments (nuclear waste storage, human space missions, nuclear reactor operations).

In this study, we have assessed bond breakage and molecular rearrangement after exposure to MeV ion beams of hydrogen (to simulate both recoil protons or fast neutrons) and helium (to simulate both alpha emitters and ejected He nuclei by high energy particles). Powders of glucose (with and without attached fluorine) and films of bovine DNA (dissolved in water, then dried on a silicon wafer) were exposed to various ion beams using a National Electrostatics 5SDH-2 ion accelerator. X-ray photoelectron spectroscopy (XPS) was used to measure compositional changes from irradiation-induced loss of volatile species (particularly O, F, and N-containing fragments). In agreement with published studies, DNA degradation broadly correlated with the total amount of energy deposited in the dried film, regardless of ion species or energy, with evidence that DNA base pairs are preferentially degraded in this circumstance. When assessing glucose degradation, however, slight differences were noted which may be ascribed to additional degradation effects of a resonant nuclear reaction.

Abstract 93 Poster - Poster Sessions

First Experimental Verification of Einstein's $E=mc^2$ by Cockcroft and Walton: Re-visited

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Cockcroft and Walton reported first legendary experiment in 1932 for confirmation $E=mc^2$ after 27 years of its theoretical derivation. The developments of experiment can be reported in three stages. Firstly, when Cockcroft reported experiments, using masses of proton (1.0072u), ^{7}Li (7. 0104u) and alpha particles (4.0011u) existing at that time, the percentage deviation from predictions of $E=mc^2$ was found 16.594. Secondly, when Brainbridge measured the mass of ^{7}Li equal to 7.0130 u (0.03 % higher then used by Cockcroft), then percentage deviation reduced to 2.291 as reported by Cockcroft. Thirdly, using current values of masses of proton i.e. 1.007276466621u (0.0075% higher than used by Cockcroft), ^{7}Li i.e. 7.01600455u (0.07994% higher than used by Cockcroft), alpha particles (0.010149%) the percentage deviation increases to 9.767 if the value of energy per disintegration is regarded as 17.2 MeV. This discussion in no way doubts the various established applications of $E=mc^2$. Thus as this experiment is regarded as established in various stages, so this experiment can be finally repeated taking the latest value of the data and the latest sophisticated equipment.

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Sensitization effects of In-Vitro Breast Epithelial cells to Proton Irradiation by PEG-coated Gold Nanoparticles

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Exploration into the enhancement of cancer treatment has garnered interest for more than 50 years. These enhancements all share the same goal: a method to spare healthy surrounding tissue while enhancing killing of cancerous tissue. We report in this work on our resent results using metallic nano-particles as radio-sensitizers in the treatment of malignant breast (MCF7) epithelial cells. Specifically, polyethylene glycol (PEG)- coated gold nanoparticles (GNPs) are studied as potential radiosensitizers in MCF7 cells irradiated by energetic protons. The cells are irradiated in the ion beam faciltily at East Carolina University using the 2-MV tandem Pelletron accelerator the micro-beam line, which has been adapted to irradiate a monolayer of cells with doses ranging up to 10 Gy. The cells are plated and cultured onto custom 15-well plates 48 hrs prior to irradiation. Twenty-four hours prior to irradiation, the cells are incubated in the presence of the PEG-coated GNPs at a concentration of 34nM, allowing integration of the GNPs to the monolayer of cells. Cells are treated with the GNPs for 24 hrs prior to irradiation, and cell viability is subsequently measured using the PrestoBlue metabolic assay. Survival curves for the meligant breast cells will be presented.

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The Radiosensitization Effect of Pegylated Gold Nanoparticles in Prostate Carcinoma Cells with Proton Irradiation

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One of the main goals of cancer radiation therapy is to reduce the dose to healthy tissues while maximizing the dose to malignant tissue. A special class of materials known as "radiosensitizers" has emerged that can help achieve this goal by increasing the response of cells and tissues to radiation. High-Z metallic nanoparticles, such as gold nanoparticles (GNPs), have been studied as radiosensitizers. The application of these nanoparticles to cancerous cells has been shown to result in an increase in celling killing, primarily due to DNA damage from enhanced secondary electron emission. An important parameter of GNPs is the applied surface coating which effects their biocompatibility. Polyethylene-glycol (PEG), in particular, has been shown to be an advantageous coating for gold nanoparticles by increasing biocompatibility.

This research explores the use of PEG-coated GNPs as radiosensitizers in prostate carcinoma cells (22Rv1). The cells are cultured and plated in customized plates in the ECU Cell Culture Laboratory and treated with the GNPs in concentrations varying from 0-68 nM 24 hours prior to irradiation to allow for optimum cellular uptake. A new cell irradiation beamline has been constructed in the ECU Accelerator Laboratory which houses a 2-MV Tandem Pelletron Accelerator. A 3-MeV proton beam is generated to irradiate the cells with doses ranging from 0-10 Gy. Results from a metabolic assay are used to construct survival curves of the cells with the varying concentrations of PEG-coated GNPs along with their controls to illustrate the radiosensitization effect.

By enhancing the sensitivity of the cells to radiation with these PEG-coated GNPs, the overall dose applied to patients undergoing radiation therapy could be lowered while still effectively killing the cancer cells. This reduction of dose would spare surround healthy tissue resulting in fewer side effects for patients.

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Doping of 2D materials by Ultra-low Energy Ion Implantation

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The ongoing development and current status of ultra-low energy ion implantation for the doping of graphene and transition metal dichalcogenides (TMDs) is described. For successful implantation in 2D materials, the ions are decelerated as low as 10 eV before impinging on the target. A new deceleration unit ensures that only part of the sample is irradiated by electrostatic masking, and thus a concentration gradient can be implanted without the need of a physical mask to ensure surface integrity (1)For demonstration purposes, ion optical simulations were made and compared with experiments of 25 eV Mn on ta-C. With the help of RBS measurements, it is shown how the masking influences the amount of introduced Mn. In addition, an ion source combining a hot filament hollow cathode source with a sputter source was developed to provide ion beams of a wider range for the implantation (2)An advantage of this source is that ion beams can be generated from low vapor pressure elements such as Mo. By test implantation with ultra-low energy (20 eV) in ta-C, we observe that these elements are suitable for implantation in 2D materials. After implantation, the elements were verified by RBS and PIXE measurements. As a first step towards an implanted pn-junction in graphene, laterally controlled implantation was used to implant B with 20 eV and a fluence of up to 5e14 at/cm^2. Subsequently, the surface potential was determined along the sample by scanning kelvin probe microscopy to investigate the transition region.

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Effect of Nitrogen Ion Incorporation into Indium Antimonide Nanoribbons

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InSb is a narrow direct band gap semiconductor that has its spectral response in the infrared (IR) range of about 5 - 6 μm. When N is incorporated into InSb, a semiconductor to semi-metal transition occurs for ≈ 2% N and the cut-off wavelength shifts to the LWIR region. Intrinsic InNSb has a high absorption coefficient of 3-6 x 10^4 cm^{-1} in the LWIR range from 10-20 μm. In spite of the decrease in E_g, the conduction-band's effective mass increases with N content; due to interaction of the localized N-states with extended states of the conduction band. In this work, we report on the growth of InSb nanoribbIons in a CVD system. 45 KeV N ions were implanted into the nanoribbon to achieve 1% doping.

Structural and electrical characteristics of the InSb nanoribbons before and after N implantation will be presented. The nanoribbons have length of the order of 20 μm, width of 1 μm and thickness of about 200 nm. This work is interesting since it facilitates development of long-wavelength infrared (LWIR) photon detectors that operate in the 8-14 μm atmospheric windows and are a critical component in many military/civilian imaging systems.

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